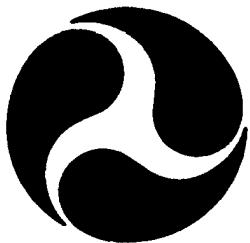


Report No. CG-D-08-96

**Analysis of the Causes of Chemical Spills
from Marine Transportation or Related Facilities**

**Danny Whitaker-Sheppard
Eric Kallen
and
Thearin Wendel**

**Booz-Allen & Hamilton Inc.
8283 Greensboro Drive
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**FINAL REPORT
March 1996**

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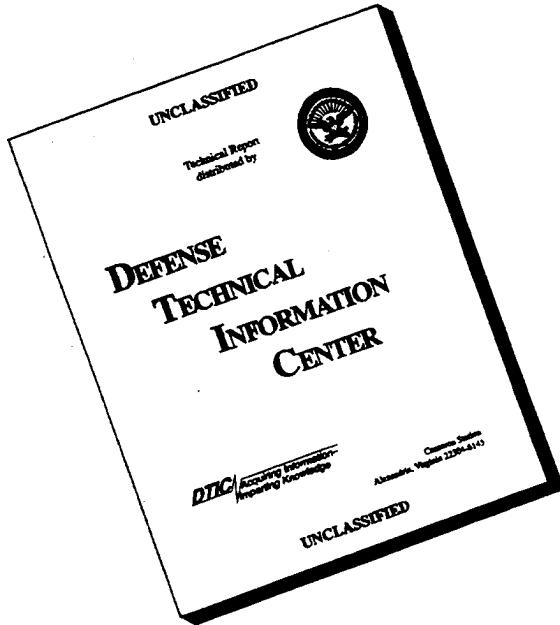
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16. Abstract This report describes the results of a study of the causes of chemical spills from vessels and facilities for the U.S. Coast Guard. The purpose of the report is to identify the chain of events that lead to spills and the frequency of these spills in order to identify potential methods of preventing spills. The data for this study were collected through visits to six U.S. Coast Guard Marine Safety Offices, review of Federal and State databases, and review of literature sources. The potential causes that were considered included human error, equipment failure, structural failure, and weather. Other characteristics of spills examined included time of day, location, and substance. The Management Oversight and Risk Tree (MORT) analysis technique was used to complete the analysis. The results of the analysis led to a number of conclusions and recommendations for the prevention and mitigation of marine chemical spills in the future.			
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Approximate Conversions to Metric Measures		Approximate Conversions from Metric Measures														
Symbol	When You Know	Multiply By	To Find	Symbol	When You Know	Multiply By	To Find	Symbol	When You Know	Multiply By	Length	Area	Mass (Weight)	VOLUME	Temperature (Exact)	Temperature (Exact)
in	inches	* 2.5	centimeters	cm	mm	millimeters	0.04	in	inches	inches	in	in ²	square centimeters	0.16	°F	°C
ft	feet	30	centimeters	cm	cm	centimeters	0.4	ft	inches	feet	ft	yd ²	square meters	1.2	°C	°F
yd	yards	0.9	meters	m	m	meters	3.3	yd	feet	yards	yd	mi ²	square kilometers	0.4	°F	°C
mi	miles	1.6	kilometers	km	km	kilometers	1.1	mi	yards	miles	mi	mi ²	square miles	0.6	°C	°F
in ²	square inches	6.5	square centimeters	cm ²	cm ²	square centimeters	0.16	in ²	square inches	inches	in	in ²	square centimeters	0.16	°F	°C
ft ²	square feet	0.09	square meters	m ²	m ²	square meters	1.2	ft ²	square yards	feet	ft	yd ²	square yards	1.2	°C	°F
yd ²	square yards	0.8	square meters	m ²	m ²	square meters	0.4	yd ²	square kilometers	yards	yd	mi ²	square kilometers	0.4	°F	°C
mi ²	square miles	2.6	square kilometers	km ²	km ²	square kilometers	2.5	mi ²	hectares (10,000 m ²)	miles	mi	mi ²	hectares (10,000 m ²)	2.5	°C	°F
oz	ounces	28	grams	g	g	grams	0.035	oz	ounces	ounces	oz	fl oz	fluid ounces	0.03	°F	°C
lb	pounds	0.45	kilograms	kg	kg	kilograms	2.2	lb	pounds	pounds	lb	c	cups	0.125	°C	°F
	short tons (2000 lb)	0.9	tonnes	t	t	tonnes (1000 kg)	1.1		short tons	short tons		pt	pints	2.1	°F	°C
tsp																
tbsp																
fl oz																
c																
pt																
qt																
gal																
ft ³																
yd ³																
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C	°C	Celsius temperature	9/5 (then add 32)	°F	Fahrenheit temperature	°F	°C	°F	°C	°F	°C	

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EXECUTIVE SUMMARY

PURPOSE

The purpose of this report is to provide information to the United States Coast Guard (USCG) on chemical spills for determining the needs for research involving hazardous materials spill countermeasures and prevention. This report supports the Department of Transportation's strategic plan by investigating how to significantly improve the safety of transporting hazardous materials on our water transportation network through technical solutions. Regulatory changes or additions were not considered as a tool to address the issues identified in this investigation.

ANALYSIS

The Study Team analyzed data from spill data bases, newspaper articles, and port visits. This resulted in a breadth of data ranging from long-term historical data to more recent data from field inspectors and responders. The Management Oversight and Risk Tree (MORT) model analysis technique was used to determine causes and conditions which are most often associated with significant chemical releases. This analysis was chosen based on the data quality and the level of detail in the data.

MORT analyzes individual and group accident and incident data after-the-fact, from a management perspective, to determine the "root causes" associated with accidents. MORT analytical techniques were developed by the U.S. Atomic Energy Commission and the U.S. Department of Transportation. This analysis is a top-down, broad-based management perspective for identifying, analyzing, and preventing significant chemical spills similar to those that have happened in the past. It is also a detailed root analysis of the most common spill scenarios which provides a bottoms up approach for identifying direct and root causes for various vessel service types. This results in more complete information regarding the causes of chemical spills and what research and development projects could be initiated to develop effective countermeasures for or prevention of chemical spills.

RESULTS

The results of the study show that research and development is necessary to investigate potential technologies and methods for preventing future spills of hazardous materials. Research is necessary because there is the potential for significant consequences from a hazardous material spill. It also appears that research regarding prevention of spills may have a high return. This is because most spills have similar causes and technology exists in other transportation modes that could be adapted for marine practices.

Using the MORT model and detailed root tree analysis, the Study Team determined that the cause of most spills is human error associated with equipment failures. As a result, the primary recommendation is to conduct research on human factors focusing on human behavior, abilities, limitations, and other characteristics to design equipment, and systems that prevent human error. This would enable improvements in human controlled operations. Human controlled operations have become increasingly important with the increasing complexity and speed of technology. Humans are relied upon for prevention actions (e.g., proper inspection and testing of equipment), operations (e.g., navigating safely through U.S. waterways), and for response actions during abnormal and emergency operations. Examples of this research include:

- Controls - gauges, alarms, hose hookups, layout of controls
- Work environment - warning signs, placarding, physical comfort, noise, temperature
- Staffing - minimum needs, overtime, training, and communication of risk
- Instrumentation - sufficient, timely, reliable, understandable

Failed or inadequate equipment is a major direct cause of spills that can be eliminated through changes to equipment and or new technologies. The data also indicated that prevention equipment was apparently not in place to prevent spills. Equipment to address these issues include:

- Vapor recovery systems and closed system requirements
- Improved alarms
- Improved pressure relief valves
- Hose engagement gaskets

In summary, spill prevention research should focus on two areas: improvement to equipment and human factors analysis. In some cases, new equipment technology could improve both the equipment and human factors. An example is improving overflow alarms to enable them to more accurately reflect the level of the liquid and increase the operator reliance on the alarm versus visual observation.

The other recommendations are divided into several categories: spill prevention; information systems; and inspection operations and procedures. Each of these categories has implications for research and development, and most may have potential implications for regulatory development and current operations.

Chapter I: Introduction

This report provides information to the United States Coast Guard (USCG) on the causes of chemical spills. This information may be used by the USCG to determine research needs and priorities involving hazardous materials spill countermeasures and prevention, as well as, to update current operations within each Marine Safety Office (MSO).¹

This report supports Goals Four and Five of the Department of Transportation's Strategic Plan:

- Goal 4 - Promote Safe and Secure Transportation
- Goal 5 - Actively Enhance Our Environment

The overall objective of these goals is to minimize the dangers to communities and industry associated with the transportation of goods and harmonize transportation policies and investments with environmental concerns. This report also supports the objective of significantly improving the safety of transporting hazardous materials using our air, water, surface, and pipeline transportation network.

This report was requested in response to a May 1993, hazardous chemical response workshop held in Yorktown, Virginia, to identify the requirements and scope that a research and development program for hazardous materials should consider. At the workshop, USCG personnel determined that significant new knowledge existed regarding hazardous materials spills and that a survey of past spills identifying the causes and nature of spill failures should be conducted. This survey would be used to identify significant transportation or storage problems requiring technological solutions.

To complete this survey, information was gathered for this report on the frequency and causes of hazardous materials spills. Data were gathered through government records and data base searches, interviews, and record searches at six MSOs and one USCG National Strike Team. The information gathered was analyzed through a combined approach using a top-down and bottom-up analysis. This approach evaluates both management and job-specific event factors having a bearing on chemical release accidents. The Study Team's analysis of the survey's findings enabled the identification of the direct causes of spills and many of their associated root causes and other spill related characteristics. Based on these results, the study team identified recommendations for further research and other changes.

¹ The scope of the investigation requested by USCG specifically excluded analyzing causes of oil spills and considering regulatory revisions as a tool to address the issues identified in this investigation.

The remaining chapters of this report describe in detail the background, analysis, and results of this study. The other chapters in this report are:

Chapter II: Background and Sources For Chemical Spill Data

This chapter describes the process for collecting hazardous material spill incident and vessel traffic data and presents data collection results.

Chapter III: Analysis

This chapter describes the Management Oversight and Risk Tree (MORT) analysis. It describes the methodology, findings, and results; additionally, it describes common spill scenarios.

Chapter IV: Conclusions And Recommendations

This chapter combines the results of the analyses with the findings regarding common spill scenarios and presents the overall results and conclusions. This chapter then describes the recommendations for future spill prevention efforts. The recommendations are divided into several categories including future research directions and operations.

In a report under separate cover, the Study Team provided the USCG with a copy of the chemical spill incident report data base system.

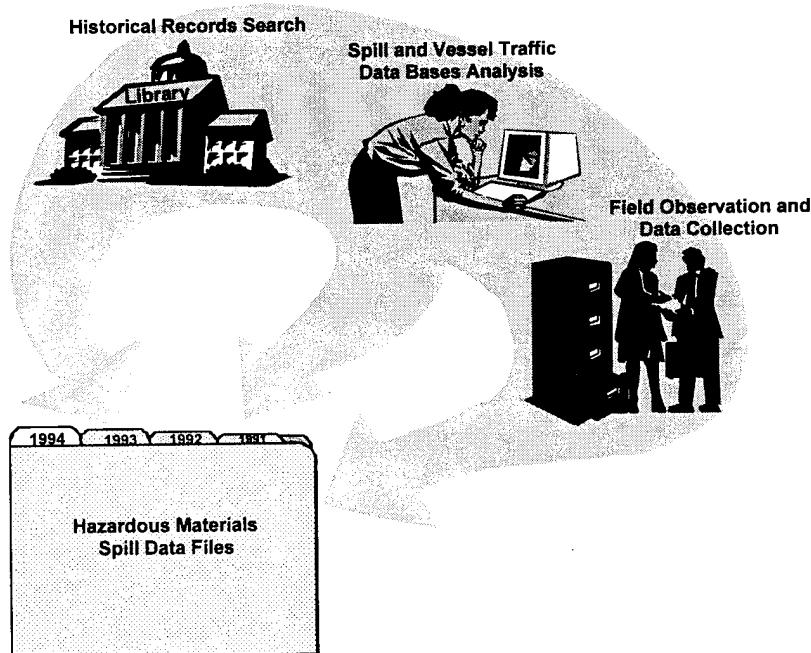
Chapter II: Background and Sources For Chemical Spill Data

This chapter presents a summary of the data collected for this study. First, the data gathering approach is outlined. Second, the data collected on marine spills of hazardous materials are summarized. Third, the chapter describes the limitations found in the available data and how the Study Team mitigated them. Finally, a discussion of the underlying traffic volume data provides the context of the spill data.

1. Data Was Collected From Three Complementary Sources to Provide an Overall Picture of Marine Chemical Spills

A three-pronged approach was used to capture all relevant information regarding number and causes of chemical spills. This approach covered three general areas: historical reports; existing spill and traffic incident data bases; and personal interviews, as illustrated in Exhibit 2-1.

Exhibit 2-1: Three Sources for Data Collection

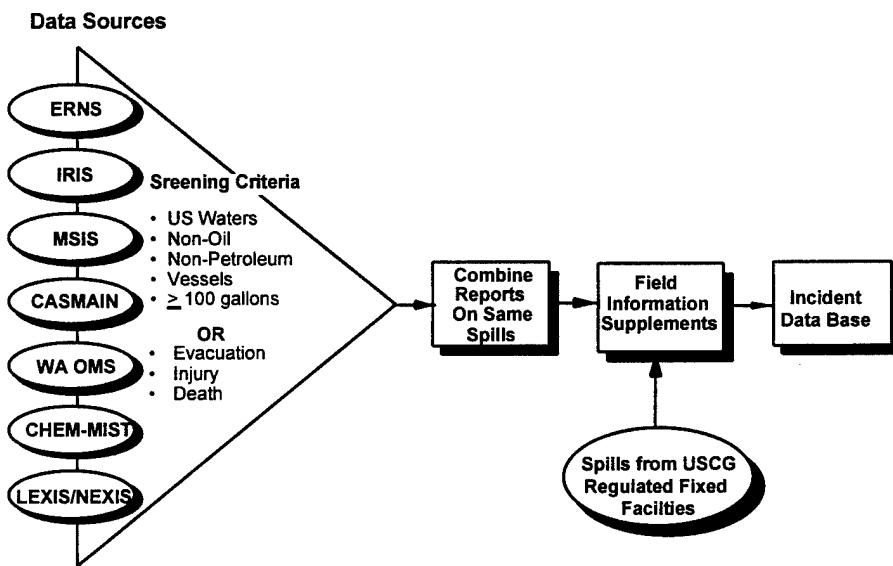


Multiple data sources were examined because no one source is comprehensive in either accuracy, level of detail, or completeness. Results of data searches from various sources were combined to develop the most comprehensive chemical spill data base possible. Each data source used to capture spill data is described separately in this chapter in order to provide a full picture of the strengths and weaknesses presented by each source. The aggregated data base is analyzed in the next chapter.

1.1 Screening Criteria Were Used to Focus the Search for Significant Marine Chemical Spill Reports

This study developed a chemical incident data base of significant spills of hazardous materials using screening criteria. The screening criteria were used to determine applicable spill reports from each data source. The process for collecting and screening data is shown in Exhibit 2-2.

Exhibit 2-2: Flowchart for Data Base Development



The screening criteria are described below.

- US Waters - This eliminated spills outside of the regulatory jurisdiction of the USCG.
- Non-oil, Non-petroleum - This eliminated crude oil, other oils, and petroleum products from the data base.
- Vessels - All vessels are regulated by the USCG. The USCG regulates fixed facilities, but most USCG responses to spills from fixed facilities are for facilities or parts of facilities regulated by the United States Environmental Protection Agency (US EPA). At the national level, it is generally impossible to distinguish between USCG regulated and US EPA regulated facilities. Visits to MSOs enabled the identification of 17 spills from regulated facilities.
- Minimum of 100 gallons released - Causes of smaller spills were considered less likely to be reported on a consistent basis or to result in injuries or response actions. Spills of less than 100 gallons that did result in physical harm were included by the evacuation, injury, or death criteria.
- Evacuation, Injury, or Death - Any non-oil, non-petroleum spill from vessels regardless of size that caused an evacuation, injury, or death was included in the data base.

1.2 Information from the Reports Was Collected on a Standard Form to Aid in Comparing Reports

Following collection of the raw data from each data source, the spill reports were compared to link separate reports concerning the same spill and to reduce data gaps. The information from the reports is captured on the Standard Spill Incident Report Form (see Exhibit 2-3 on the following page). Data fields in the spill reports include:

- Date
- Location
- Material
- Quantity
- Vessel/Facility
- Operation in Progress
- Causal Factors²
- Response Actions
- Responsible Party
- Comments

The chemical incident data base resulting from this effort was provided to the USCG in a report under separate cover.

² Interpretation of the original data from various sources regarding the cause of a spill was required because the data sources used different standard lists of causes of spills. These were categorized as primary, secondary, and contributing causes.

Exhibit 2-3: Chemical Spill Incident Report

Tier ranking system categorizing
hazard of spill

U.S. Coast Guard - Chemical Spill Incident Report		
Report #:	Spill Ranking:	MSIS #:
Spill Date: Day of Week: Spill Time	State: Body of Water: Latitude:	City: Longitude:
Material Released: CHRS Code: Actual Spill Size: Potential Spill Size.		
Transportation Description: Operation: Primary Cause: Secondary Cause: Contributing Cause: Contributing Cause2:		
Vessel/Facility Name: Vessel/Facility ID#: Vessel Flag: Vessel Service: Type of Propulsion:	Year Built: Gross Tons: Length (feet): Depth (feet): Breadth (feet):	Spill Narrative:

Unique project identification number

Related USCG case number

Background information on time and location of spill

Specific information on material spilled

Detailed causal factors and operations in progress at time of spill

Specific vessel information downloaded from MSIS

Miscellaneous spill narrative taken from various spill reports. Typically containing response actions, events leading up to the spill, responsible party, etc.

2. Data Gathering Efforts Resulted in Several Relevant Previous Studies and 329 Significant Marine Chemical Spills

The data gathering effort revealed that more than 30,000 spills are reported annually. Of these, more than 50% are oil spills, and hazardous material spills account for about 45%. Only 10% of all spills reach water, and only about 1% are from vessels. Of this 1%, most of these spills are reports of substances thought to be hazardous in quantities of less than 100 gallons from an unknown source. These spills are not used in this study because their veracity is questionable, they provide no additional data related to the cause or source of spills, and their impacts were limited. The resulting data base is of 329 spills into water with some other key information.

2.1 Historical Records Provided Limited Data

The first phase of the data gathering effort involved a search of historical reports and other technical literature for listings and methodologies for analyzing causes of spills. The primary data search was made through the National Technical Information Service (NTIS) for all reports concerning hazardous material releases.

2.1.1 Three Studies Provided Information on Causes of Chemical Spills

The Study Team reviewed abstracts of more than 300 publications that addressed hazardous material spills. It was determined that few of these reports addressed marine spills specifically or in depth. The Study Team did identify three publications containing data on causes of maritime spills that were relevant to this investigation. These sources were used as the research baseline:

- **Hazardous Material Spills: A Documentation and Analysis of Historical Data**-- This 1978 US EPA analysis of fixed facilities under their jurisdiction provided information on modeling and classifying spills of hazardous materials.
- **"The Human Element in Marine Safety"**-- This 1994 article in *Surveyor* discussed the human factors involved with marine-related spills.
- **Report on the Maritime Transport of Hazardous and Noxious Substances**-- This 1991 report from the Department of Transportation contains information on vessel traffic, causes of spills, and a data base of oil and hazardous material spills.

Two other reports were identified concerning an analysis of tanker casualties and a multivariate model explaining causes of maritime accidents. These reports were published by the National Oceanic and Atmospheric Administration (NOAA), but are not available in the NOAA library or from NTIS. The documents could not be located through discussions with NOAA personnel.

2.1.2 Literature Searches Yielded Information on 15 Relevant Spills

One data source was newspaper articles on specific incidents identified using the on-line LEXIS and NEXIS systems. This resulted in articles on 15 spills that met the screening criteria. Several of the earlier articles described spills not found in spill data bases. Later articles provided additional data concerning records in the spill data bases. This included some additional detail concerning the cause of the spill and in particular the response to the spill.

This was supplemented by an inspection of the National Safety Council's records of the worst spills in history. Newspaper articles were reviewed to determine that these spills were not relevant to the scope of this study.

2.2 Data Bases Were Determined To Contain 320 Relevant Chemical Spill Reports

Seven data bases were identified that capture data regarding hazardous material spills. Each data base was reviewed for level of detail and relevance to the marine environment. Based on this review, six data bases were used to identify spills and causes of spills (see Exhibit 2-4).³ Please refer to Appendix A for more information regarding the review of Federal data base causal information.

Exhibit 2-4: Hazardous Material Spill Data Bases

Data File	Organization	Number of Records	Timeframe Covered	Number of Applicable Records	Highlights
ERNS	US EPA	>320,000	1987-1995	80	Comprehensive collection of spill data Data gathered from EPA Regions, DOT, USCG, and NRC Very little data on causal factors Only initial data, no verified data Data can be manipulated to identify trends
MSIS	USCG	>100,000	1985-1991	75	Information on primary and secondary causal factors Data linked to CASMAIN and IRIS Difficult to manipulate data and identify trends
IRIS	NRC	>100,000	1991-1995	70	Majority of data is subset of ERNS Data linked to CASMAIN and MSIS Limited vessel data Data prior to 1991 difficult to sort and download
CASMAIN	USCG	>100,000	1985-1990	75	Cursory vessel information provided Data base supplements MSIS Data available on casualties
CHEM-MIST	USCG	233	1970-1990	15	Data gathered to support the "Report on Maritime Transport of Hazardous and Noxious Substances" Data gathered by comprehensive search of periodicals and newspapers Data available only at summary level
WA OMS	Washington State	500	Not Specified	5	Data limited to waters in and around Washington Data gathered to support inspection screening Limited information recorded in data base

2.3 Spill Report Information was Augmented by Interviews With Marine Experts and Field Data Gathering

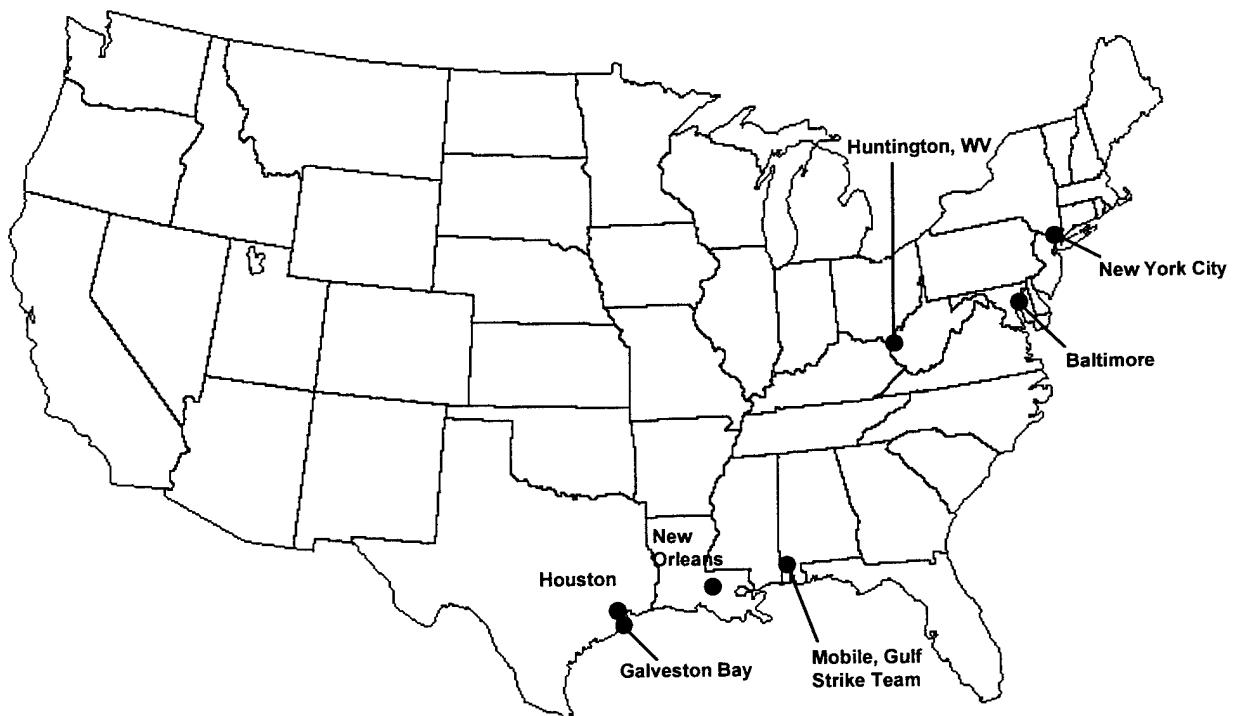
Following collection of historical data on spills from records, reports, and data bases, additional information was collected from six MSOs and one Strike Team. The information came from reviews of MSO records about past spill incidents and from discussions with USCG personnel. This information was used for several purposes:

³ A data base available from Lloyds of London was excluded due to uncertainty concerning whether the data base contained relevant data and the cost of conducting searches using the data base.

- Verify the information collected from the national data bases
- Include any additional information or spills
- Visit facilities and vessels and accompany inspectors on inspections
- Collect information on vessel traffic statistics

The six MSOs and one Strike Team that were visited are shown in Exhibit 2-5. These offices were chosen as representative of the broad range of ports regulated by the USCG. For example, Houston and New York City are two of the busiest ports in the United States. Baltimore handles large quantities of containers, and Huntington handles exclusively barge traffic on inland waterways.⁴

Exhibit 2-5: MSOs and Strike Teams Visited



Each site visit included:

- Reviewing maps of the port, including the USCG regulated waterways and hazardous chemical facilities.
- Meeting with MSO and port personnel to gain an understanding of the common causes of spills and normal activities associated with the port.

⁴ A west coast port was also targeted, however USCG personnel were unavailable during the course of the study to support a site visit.

- Meeting with chemical facility personnel to discuss common causes of spills and areas of concern.
- Reviewing all records of hazardous material spills from vessels and applicable fixed facilities maintained at the MSO against the national data base information.
- Accompanying USCG inspection teams and facility personnel on tours of several regulated facilities and vessels at the port.

2.3.1 Site Visits Identified Spills from Fixed Facilities

The review of the records and maps along with interviews of MSO personnel enabled the identification of 17 records of spills that met the screening criteria from fixed facilities. These spills were not identified from the data source reviews because it was not possible to distinguish if the USCG was the regulator of the fixed facility. This review also showed that most spills that occur involving vessels and fixed facilities are reported as a vessel spill.

2.3.2 Site Records Concurred with National Federal Data Bases

By reviewing the records at the MSOs with the data bases, it was found that a record for each spill existed in the Federal data bases. In general, most of the spill cause information available in the records was contained in the data bases. However, in several cases the records contained additional data concerning the cause of the spill and, in particular, the response to the spill.

2.3.3 Highlights of Each Site Visit

The site visits are described alphabetically below.

MSO Baltimore (Baltimore, MD)

MSO Baltimore is responsible for regulating vessels and facilities in an area that includes much of Baltimore; Washington, DC; the Chesapeake Bay; and Potomac River. Under its jurisdiction are five waterfront chemical facilities that are involved with bulk chemical operations (Peridot Chemical, S.C.M. Glidden Pigments, ST Services, W.R. Grace Company, and Vista Chemical).

The Port of Baltimore is also responsible for regulating three container facilities (Dundalk Marine Terminal, Seagirt Marine Terminal, and North & South Locust Point Marine Terminals). In 1993, these container facilities moved more than four million tons of container cargo, of which it is estimated that 5-7% contain hazardous chemicals. The Seagirt Marine

Terminal is a newly renovated, state-of-the art container facility that is in operation from 7 a.m. until midnight five days a week. The terminal is located on the north shore of the Patapsco River. In 1994, this facility handled 354 container ships (in 1995 they had handled 230 through July 25). MSO personnel are responsible for both inspections and response actions at these facilities. MSO personnel reported that the largest hazard from containers is inspecting or responding to leaking containers that are not properly labeled in accordance with DOT regulations. Additionally, with the large number of containers moving through these facilities, the inspection program can only capture a small percentage of these violations.

Data identified in this site visit include that in 1994 MSO Baltimore responded to 490 spill incidents. Less than 10% of these incidents involved chemicals and none involved a spill larger than 100 gallons, deaths, injuries or evacuations. As a result, few spill records were identified as meeting the criteria set for this study.

MSO Galveston (Galveston, TX)

Located on the Gulf of Mexico, MSO Galveston regulates a large number of chemical facilities, oil facilities, container facilities, and vessel traffic traveling through the Houston Ship Channel, the Gulf Intercoastal Waterway, and Galveston Bay. Included in these facilities are BASF, Dow Chemical Company, Amoco Chemical, Union Carbide, and Sterling Chemical. One of the largest of these facilities is Dow Chemical Company's Oyster Bay Plant.

The Dow Chemical plant is equipped with 11 marine docks capable of servicing both tank barges and tank ships. This facility has recently completed work on a new chemical dock. The dock and associated pipings and equipment cost in excess of \$30 million and include state-of-the-art technologies, such as vapor recovery systems. Additionally, the facility handles 105 different chemical products that can be stored in any of the facility's 57 storage tanks. In 1994, the facility's Marine and Terminal Operations handled 284 tank ship and 2,378 tank barge transfers. These transfers equated to more than six million tons of chemicals⁵, with only one spill incident. This incident was a minor spill of styrene from an overfilled tank on the "Panam Querda".

⁵ This is an example of data inaccuracies in vessel traffic data. This data from the facility on tonnage shipped is ten times greater than the US Army Corps of Engineers estimates for the total tonnage shipped through the whole port.

Located only 40 miles from the Port of Houston, much of the barge and tank ship traffic bound for Houston must pass through this MSO. The barge and tank ship traffic, coupled with the chemical and oil activity in the Galveston/Freeport area, resulted in the need for responses to 1,065 spill incidents between January 1993 and March 1995. Only 10-20% of these incidents were chemical related, and about half of the 10-20% satisfied the criteria for inclusion in the study.

MSO Houston (Houston, Texas)

MSO Houston is responsible for regulating one of the busiest ports in the United States, the Port of Houston. The Port of Houston is a 25-mile long complex of public and private facilities located along the Houston Ship Channel, less than three hours sailing time from the Gulf of Mexico. Houston leads the nation in foreign waterborne commerce and is one of the world's ten busiest ports, receiving more than 5,000 vessels annually.

In addition to the transfer of bulk liquids, another area of concern for MSO Houston are containers. Since June 1994, the MSO has inspected 692 containers, finding 133 deviations from USCG requirements. Most of these discrepancies are remedied "on the spot", but some require the containers to be returned to the packer or shipper for corrections. Leaking cargo and improper segregation accounted for only 5% of these discrepancies, while improper placarding and documentation was responsible for more than 50%. The two areas in the Port of Houston that are responsible for most of the container traffic are the Barbours Cut Container Terminal (with five, 1,000 ft.-long container berths handling 80 percent of all containers) and the Turning Basin Terminal (a breakbulk and container terminal area which receives 2,100 ships and barges at its 37 docks annually). MSO Houston is also responsible for regulating and responding to 47 chemical facilities. Of the 390 spills that MSO Houston responded to in 1994, only 56 (14%) involved chemicals.

MSO Huntington (Huntington, WV)

Located at the meeting point of the Ohio, Big Sandy, and Kanawha Rivers, MSO Huntington is responsible for regulating a large amount of tank barge traffic using the inland waterways between points north and south of this area. While serving as a primary stopping point for coal, coke, and petroleum products moving down from Pittsburgh, MSO Huntington is also the base of operations for many large chemical plants. For this reason Huntington is commonly referred to as "Chemical Valley."

Plants that are located in this area include: Union Carbide; Rhone Poulenc; Aristech Chemical; DuPont Chemicals; Shell Chemical; Monsanto Chemical; and P.B. & S. Chemical. Of the 8,438 transfers that occurred at MSO Huntington in 1994, approximately 29% of these were hazardous chemical related, with the rest involving oil by-products. In Huntington, styrene (264 transfers) and cumene (256 transfers) were the most frequently transferred chemicals. Despite more than 2,400 chemical transfers in 1994 in Huntington, less than 1% of these transfers resulted in a spill significant enough to be included in this study.

Mobile, Alabama (Gulf Coast Strike Team)

Located at the USCG's Aviation Training Center in Mobile, Alabama, the Gulf Coast Strike Team is responsible for much of the southeastern United States, including the Gulf of Mexico. The 38 persons stationed at the Gulf Coast Strike Team (GST) respond to oil and hazardous substance spills. During a typical year, the GST will respond to between 40 and 50 spills, of which the majority are oil related. In 1993, the GST responded to 48 spills, of which only 17 involved hazardous chemicals.

MSO New Orleans (New Orleans, Louisiana)

Located at the base of the Mississippi, MSO New Orleans is the largest MSO in the Coast Guard. Tank barge traffic traveling to both points north and south must pass through this MSO's jurisdiction. Due to this fact there are more than 60 barge fleets located in this MSO. In 1994, MSO New Orleans responded to more than 2,100 spill reports, with less than 1% of these being hazardous chemical related, and only a small portion of the 1% meeting the criteria for inclusion in this report.

Captain of the Port New York (Governor's Island, NY)

Captain of the Port New York (COTP NY) is responsible for regulating activity in and around New York City, including both Upper and Lower Bay, Kill Van Kull, and parts of Newark Bay. COTP NY receives traffic from tank ships, tank barges, and container ships. Regarding the latter, COTP NY inspects more than 100 containers a month. In October and November 1994, 205 containers were inspected and 62 were found to have at least one discrepancy. These discrepancies were primarily from improper marking or placarding of the containers, although 23 involved violations of 49 CFR 176 "securing of hazmat in container".

In addition to the port's responsibilities for inspecting and responding to spills from containers, it also responds to spills from other transportation modes such as pipeline spills or spills from fixed facilities. In 1993, COTP

NY responded to 759 incidents, 886 in 1994 and 91 through the end of February 1995. Of these responses, hazardous chemicals account for less than 10%. Of these, most were considered minor incidents and did not satisfy the screening criteria for consideration in this analysis.

3. Limitations in the Available Data Included Inconsistent Reporting and Level of Detail Among Data Sources, But the Use of Multiple Sources Helped to Mitigate These Limitations

Few comprehensive studies have been undertaken to address marine spills of hazardous materials. While several data bases collect and disseminate reports on marine chemical spills, these data bases were designed for different end-purposes. As a result their information is not consistent or complete. Please refer to Appendix A for more information regarding the review of Federal data base causal information.

Despite the shortcomings of each data source, by combining each data source they provide a more complete picture of the causes of spills. The strength of the data was therefore increased by the data collection methodology, in which multiple, overlapping data sources were compared to minimize data gaps. In addition, the data gathered from the visits to the MSOs supplemented and confirmed the data captured from national data bases. Using the information collected from the visits, the Study Team compared data from inspection reports, enforcement actions, and field log books with the causes listed in the national data bases. It also confirmed that the MSOs generally do enter all available information in MSIS. In addition, since the primary data sources are official Federal or State sources, the data can be duplicated by other researchers.

Even with the multiple data sources, there were still data limitations that must be considered in future research. Causal data is generally incomplete because the causal information field is left blank or listed as unknown. Visits to the MSOs also proved that the data, including causal data, is entered into MSIS inconsistently from person-to-person and from MSO to MSO. Further, many reports were only initial notifications and did not contain verified or updated information.

4. Vessel Traffic Data Was Collected to Provide the Context of and Basis for Determining Risks of Marine Chemical Spills

Vessel traffic information is a key component in understanding the risk of an accident occurring during shipments of hazardous materials. Information regarding vessel traffic, cargoes transported, number of transfers, or the destinations of vessels is not maintained nationally or locally by the USCG. This information is essential for defining the universe of potential spills. In lieu of national USCG data on vessel

traffic, information was obtained from the MSOs and port authorities that were visited and from the US Army Corps of Engineers.

Although some MSO's receive data on traffic and cargo transfers, in most cases, this data was not maintained by the MSOs for longer than a few weeks. This information was provided at the discretion of private facility operators and may therefore be incomplete. This information may also be collected by USCG but not shared across USCG programs and organizational units.

The Port Authorities of Baltimore and Houston were visited in order to obtain information regarding vessel and commodity statistics. The port authority information consisted of detailed information on tons of commodities shipped. It did not provide complete information regarding the number of transfers of commodities or number of vessels traversing the port.

The US Army Corps of Engineers compiles information on commodities, tonnage, ton-miles, and trips. The information is kept for each lock on the inland waterways and for coastal ports. Using the information from the National Summary of Waterborne Commerce of the US, information was found on the total tonnage shipped of chemical and related products, tonnage by major waterway, tonnage of major categories of chemical information, and largest ports. Exhibit 2-6 shows that more than 100 million tons of chemical products are shipped each year on US waters.

Exhibit 2-6: Tonnage of Waterborne Commerce

Product	Tons Average for 1991 and 1992 (000s)	Percentage of Tons
Total Waterborne Commerce	2,112,100	100%
Chemical and Related Products	126,900	6.0%

Source: Waterborne Commerce of the United States, US Army Corps of Engineers: New Orleans, Louisiana; WRSC-WCUS-91 and 92.

Exhibit 2-7 shows that 90% of all waterborne chemical shipping is conducted along the Mississippi River System and along the Gulf Intercoastal Waterway.

Exhibit 2-7: Tonnage of Waterborne Chemical and Related Products

Rank	Waterway	Average tons for 1989-1992 (000s)
1	Mississippi River System (all Traffic)	42,400
2	Mississippi River System (Main Stem)	40,800
3	Mississippi River System (Internal Traffic)	32,400
4	Gulf Intercoastal Waterway	22,775
5	Ohio River System	10,050
6	Columbia River	2,950
7	Snake River	39

Source: Waterborne Commerce of the United States, US Army Corps of Engineers: New Orleans, Louisiana; WRSC-WCUS-91 and 92.

Exhibit 2-8 shows the ranking of the most frequently shipped chemical products.

Exhibit 2-8: Waterborne Chemical and Related Products Classification

Rank	Chemical and Related Products	Average Tons in 1991 and 1992
1	Fertilizers	33,013,582
2	Other Hydrocarbons	15,155,976
3	Alcohols	10,319,069
4	Sodium Hydroxide	8,605,525
5	Plastics	6,550,947
6	Benzene and Toluene	6,168,842
7	Metallic Salts	6,041,151
8	Ammonia	5,616,202
9	Chemical Additives	5,019,727
10	Sulfur (liquid)	4,610,469
11	Inorganic Elements, Oxides, & Halogens	4,130,508
12	Carboxylic Acids	3,882,483
13	Organic Compounds, NEC	3,002,278
14	Acyclic Hydrocarbons	2,982,909
15	Nitrogen Functional Compounds	2,901,083
16	Sulfuric Acid	2,565,537
17	Chemical Products, NEC	2,133,165
18	Perfumes and Cleaners	818,795
19	Wood and Resin Chemicals	702,814
20	Pigments & Paints	687,344
21	Organo-Inorganic Compounds	631,570
22	Starches, Gluten, Glue	391,223
23	Medicines	327,776
24	Pesticides	206,069
25	Inorganic Chemicals, NEC	147,701
26	Coloring Material, NEC	143,429
27	Radioactive Material	81,401
28	Explosives	59,752

Source: Waterborne Commerce of the United States, US Army Corps of Engineers: New Orleans, Louisiana;
WRSC-WCUS-91 and 92.

Exhibit 2-9 shows a ranking of the largest ports in the US by total tonnage and their estimated chemical product tonnage. Information for the eastern seaboard was not available and the national estimate of 6% of products was used as a surrogate for more exact information. This exhibit could be expanded by data on the number of spills in each of the relevant MSOs per year to provide an estimate of spills per ton of waterborne commerce. This information would allow comparison between ports of widely varying shipping totals. This was not completed because the MSO responsible for responding to each spill was not generally discernible from the information.

Exhibit 2-9: Largest Ports Ranked by Tonnage

Rank	1992 Ports Ranked by Total Tons	Average 1991-1992 Total Tons	Chemical Products by Tons (000s) 1993
1	South Louisiana, LA	194,659,556	8,045
2	Houston, TX*	137,762,566	26,506
3	New York, NY and NJ*	121,086,028	7,265**
4	Valdez, AK	96,626,409	0
5	Baton Rouge, LA	86,164,857	18,982
6	New Orleans, LA*	63,669,443	2,907
7	Corpus Christi, TX	59,959,162	4,818
8	Plaquemine, LA	56,127,583	2,247
9	Norfolk Harbor, VA	54,484,555	3,269**
10	Long Beach, CA	52,469,741	2,391
11	Tampa, FL	47,991,212	16,212
12	Los Angeles, CA	43,555,755	3,044
13	Texas City, TX	43,196,881	7,216
14	Lake Charles, LA	42,639,884	11,129
15	Mobile, AL	40,912,499	303
16	Duluth-Superior, MN, WI	38,509,618	10
17	Philadelphia, PA	38,461,882	2,310**
18	Baltimore, MD*	37,700,151	2,262**
19	Pittsburgh, PA	32,799,053	968
20	Port Arthur, TX	31,680,040	1,311
31	Huntington, WV*	19,938,008	8
48	Galveston, TX*	11,451,410	2,698

Site visits conducted.

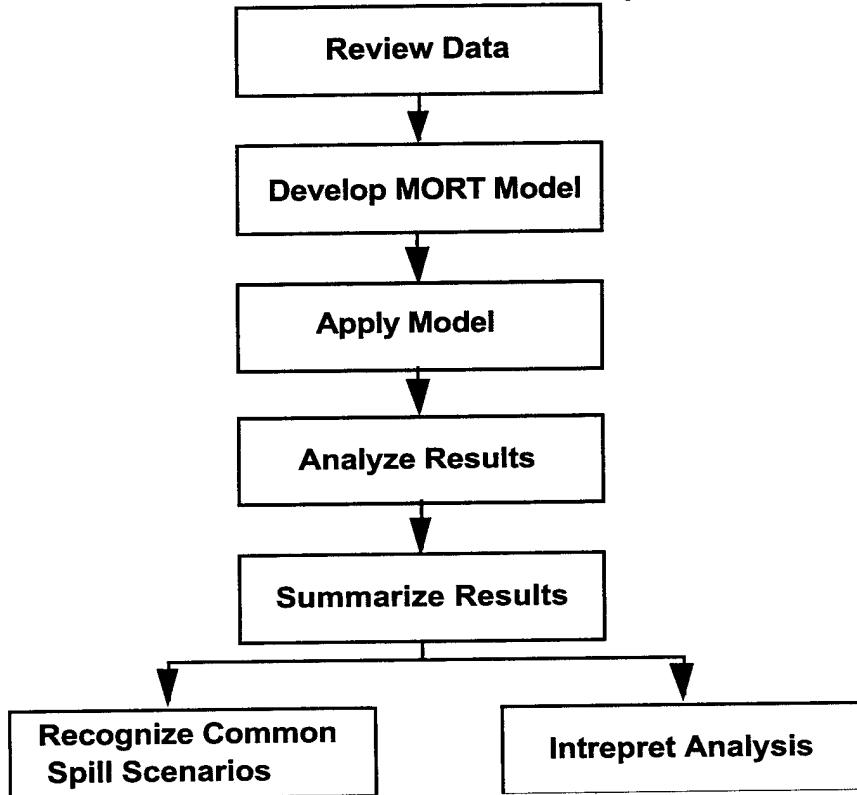
**Using an estimate of 6% of cargo was chemical and related products.

Source: Waterborne Commerce of the United States, US Army Corps of Engineers: New Orleans, Louisiana; WRSC-WCUS-91, 92, an 93.

Chapter III: Analysis

This chapter presents the analytical results of the study. To conduct the analysis, first the chemical incident data base is reviewed to identify the potential causes and characteristics of a spill. Second, this information is then used to develop a MORT model of the potential direct and root causes of spills. Third, the MORT model was applied to the chemical incident data base. This technique identifies links between direct and root causes of spills and other common characteristics of spills. The fourth step is the analysis of the results from using the MORT modeling technique. The last step presents the most common spill scenarios and a summary of the results. Exhibit 3-1 presents a flow chart summarizing the data analysis.

Exhibit 3-1: Flowchart of Analysis



1. Potential Causes, Underlying “Root” Causes, and Common Characteristics of Spills and Spill Hazard Tiers Were Identified

Using the information in the chemical incident data base, the Study Team identified the primary, secondary, and contributing causes of spills. In addition, although the cause of a spill may vary, all spills can be characterized in terms of time, vessel service, location, and status of operations and movement. The Study Team compared the frequency of causes with other causes and the characteristics. No statistically significant correlations were identified, but this review did result in identifying the potential causes and characteristics of spills.

Please refer to Appendix B for more information pertaining to statistical analysis issues.

1.1 Each Data Source Provided a Different Interpretation of Causes of Spills

Newspaper accounts and written records provided case specific descriptions of the causes of a spill. Each data base source utilized a standard list of potential causes of spills. The standard list varied between the data bases. For example, CASMAIN requests contributing causes of a spill, and ERNS only requests primary and secondary. Please refer to Appendix A for more information regarding the review of Federal data base causal information. As described in Chapter 2, this is why the reports from various sources were combined to develop the chemical incident data base. Additionally, it was found that a standard description of the causes was unavailable to the personnel entering the data in the data bases. To resolve these issues, the Study Team interpreted and refined the information from the original data sources to standard lists. A benefit of these various interpretations of causes of spills is that a wide variety of potential causes were recognized and used for the MORT analysis.

1.2 Spill Hazard Tiers Segregate the Data for Further Analysis

To determine if the causes of spills varied by the size of a spill, the spills were divided into spill hazard tiers. The Study Team assigned each spill to one of four tiers based on a ranking of spill size. The tier ranking was adjusted upwards if one of the following factors was associated with the spill:

- Evacuations, injuries, or deaths
- Potential for catastrophic loss of life, property, or damage to the environment
- Degree of response actions

Exhibit 3-2 describes the spill size associated with each tier and the final number of incidents assigned to each tier after being adjusted.

Exhibit 3-2: Hazardous Chemical Spill Ranking

Tier	Criteria	Number of Cases*	%**
Tier I:	<1,000 gallons	214 cases	65
Tier II:	>1,000 or = 10,000 gallons	58 cases	17
Tier III:	>10,000 or = 100,000 gallons	35 cases	11
Tier IV:	>100,000 gallons	22 cases	6
	Total	329 cases	100

* Assignment of Tiers modified by documentation of actual or potential for evacuation, injury, death or other damages data, and degree of response actions.

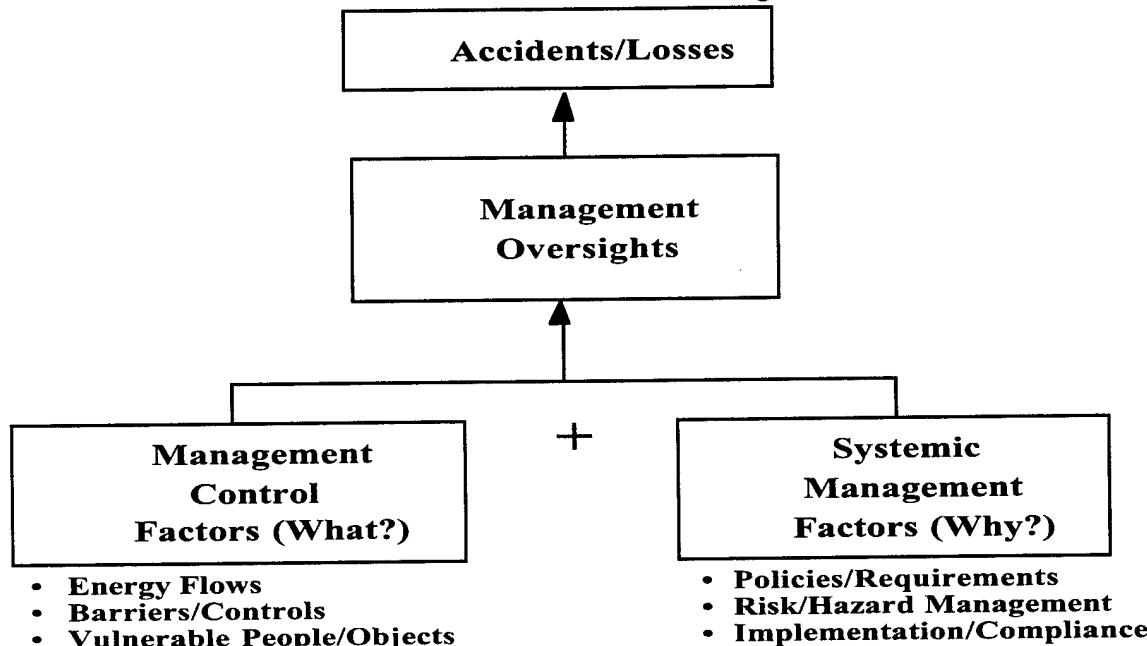
** May not total due to rounding

2. MORT Model of Marine Chemical Spills Completed

The Study Team conducted a detailed analysis of the causes of spills using the MORT analytical technique. In a MORT analysis, the root cause of an accident is considered to be related to a management decision or oversight. These oversights are divided into two categories controlled by management: specific factors which are explicitly controllable; and general factors related to the management system. Together these oversights can describe what happened during an event and why the event occurred.

The "what happened" question is analyzed by identifying potential vulnerabilities, the energy flow that activated the vulnerability, and the barriers and controls to prevent the vulnerabilities from causing a problem. The root cause for the "what happened" question is described by an event chain that includes the underlying vulnerability (e.g., loose gasket, weakened hose, intentional human act, etc.), source of energy activating the vulnerability (e.g., pumping, grounding, corrosion, etc.), and the failed barrier and control for preventing the event (e.g., improper maintenance, faulting alarm, etc.). For example, inadequate training of facility personnel in proper bulk liquid transfer procedures can be a root cause that leads to a spill through several possible direct causes, such as incomplete clearing of a transfer line before disconnection, misalignment of hose coupling before beginning a transfer, or a burst hose during a transfer. The "why it happened" question is analyzed by identifying systemic management factors which include policies, risk management decisions, and implementation and compliance with management decisions. The basic diagram for MORT analysis is depicted in Exhibit 3-3.

Exhibit 3-3: MORT Basic Diagram



The Study Team analyzed the data on characteristics and causes of spills to identify the potential vulnerabilities, energy flows, and barriers/controls associated with marine transportation of chemicals. Information for the systemic management factors was not available from the data sources. Therefore, the Study Team completed a MORT model that focuses on the "what happened" question.

3. Spill Data Translated into MORT Model and Analysis Completed

The characteristics and causes for each of the 329 spill reports were converted into vulnerabilities, energy flows, and barriers/controls. This description of each spill in MORT terms enables the identification of common root causes of spills not identifiable by analysis of the original data. Exhibit 3-4 depicts a summary of the MORT analysis. The MORT chart depicts the numbers of incidents associated with each category and subcategory. The complete MORT chart, which incorporates the available data from all 329 spills, was provided to the USCG in a report under separate cover.

4. Analysis of Results of the Application of MORT Model

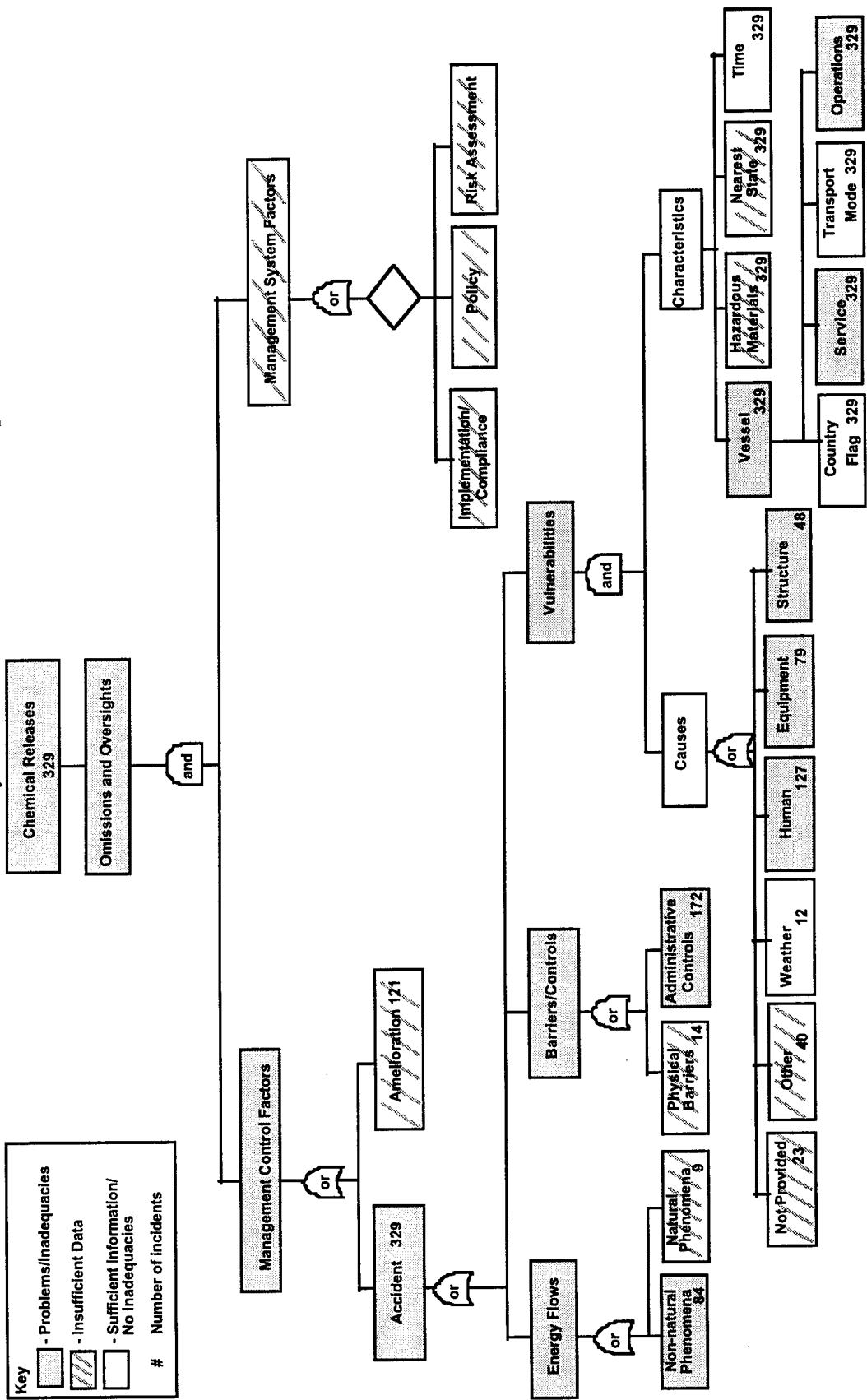
The Study Team used frequency of occurrence to examine the characteristics and causes of spills. In addition to the analysis, the results in this chapter were compared with the results in two other studies. Please refer to Appendix C for more information pertaining to this comparison.

4.1 Spills Share a Number of Common Characteristics

The information in the MSO records, newspaper articles, and data bases describes the cause and a number of other characteristics regarding each spill. These characteristics are associated with the most commonly occurring spills and may be one of the root causes of the spill. Examples of characteristics include: location; vessel service; flag; material spilled; and time-of-day.

Each of the following analyses is based on the complete data base developed from the data search in Chapter 2. The data base consists of 329 spill incidents between 1985 and June 1994. The number of spill incidents that occurred each year is depicted on the complete MORT chart. In certain analyses the total number of incidents listed is less than 329 because the data in question was unknown. The complete listing of information for each category and unknown data may also be found on the complete MORT chart or in the chemical incident data base.

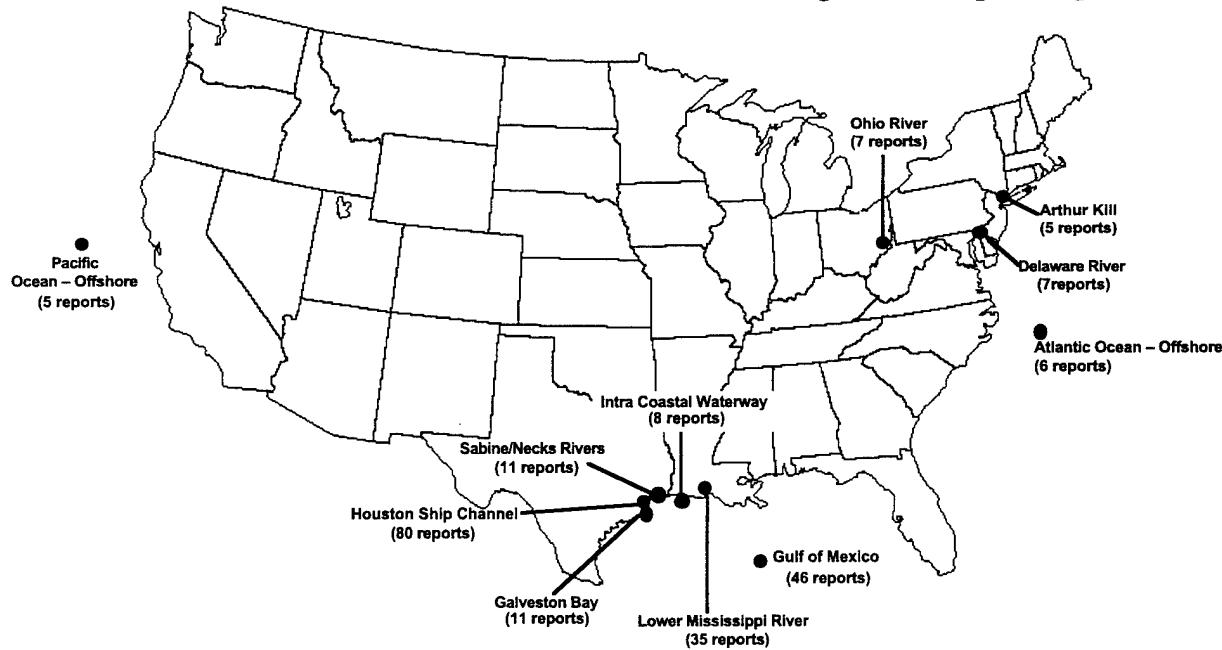
Exhibit 3-4: MORT Analysis - Causes of Hazardous Material Spills



4.1.1 58% of Spills Occurred in the Lower Mississippi, Texas, and Gulf Coast Areas

The first analysis presented is the geographic breakdown of spills. Exhibit 3-5 depicts any general location for which two or more spills are identified in the chemical incident data base. As shown, almost no spills occur in the Great Lakes region or pacific coasts and ports. The majority of spills occur in the lower Mississippi, Texas, and Gulf coast areas; this may be consistent with the proportionately larger volumes of chemicals handled in these areas. See Exhibits 2-6, 2-7, 2-8, and 2-9 for information regarding waterborne commerce traffic. This data supports the conclusion that although the hazard from shipping chemicals remains the same across the country, the risk is lower in the Great Lakes region and pacific coast due to smaller volumes of chemical shipped, less vessel traffic, and perhaps other factors such as navigational aids.

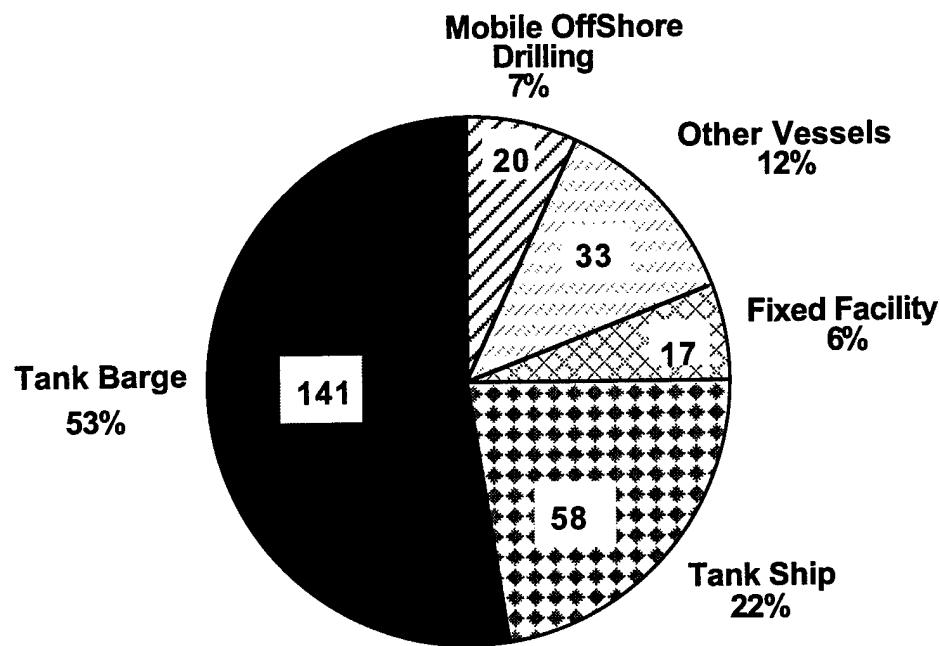
Exhibit 3-5: 11 Bodies of Water Contain 71% of Significant Spill Reports



4.1.2 Tank Barges are Involved with 53% of Spills and Tank Ships 22%

Exhibit 3-6 presents the distribution of vessel service involved with spills. Of the 269 incidents where the vessel service was known, tank barges were involved with 141 incidents or 53% of the total. Tank ships were involved with 58 incidents or 22% of the total. Other vessels accounted for 70 incidents.

Exhibit 3-6: Vessel Service Distribution



4.1.3 Acids and Benzene, Toluene, and Xylene are the Most Commonly Spilled Substances

Exhibit 3-7 shows that acids are associated with a number of smaller spills and that caustic soda is associated with larger spills. Benzene, toluene, and xylene are commonly referred to as BTX. BTX as a group accounts for a large percentage of waterborne commerce and of spills. As a sub-group of chemicals, organic chemicals account for approximately two-thirds of all chemicals associated with spills. Overall, it is unclear whether the most frequently spilled substances occur because they are frequently shipped, shipped in larger quantities, or that there is some specific difficulty involved with their shipping. See Exhibit 2-8 for information on quantities of products shipped.

Exhibit 3-7: Most Frequently Spilled Chemical Groups

Tier I		Tier II		Tier III		Tier IV	
Styrene	18	Acids	9	Caustic Soda	3	Caustic Soda	2
Acids	17	Zinc Bromide	8	Herbicide	2	Sewage Sludge	2
Benzene	17	Toluene	3	Benzene	2	Acrylonitrile	2
Xylene	14	Bilge/Ballast Water	3	Cumene	2	Groups with 1 spill	15
Alcohol	12	Xylene	3	Drilling mud	2		
Solvents	8	Ethylene Glycol	2	Toluene	2		
Toluene	7	Benzene	2	Groups with 1 spill	23		
Tallow	7	Naphtha	2				
Condensate	7	MTBE	2				
Sodium Hydroxide	7	Tallow	2				
Zinc Bromide	6	Butyl Acetate	2				
Groups with 5 or less spills	20 +	Groups with 1 spill	16				

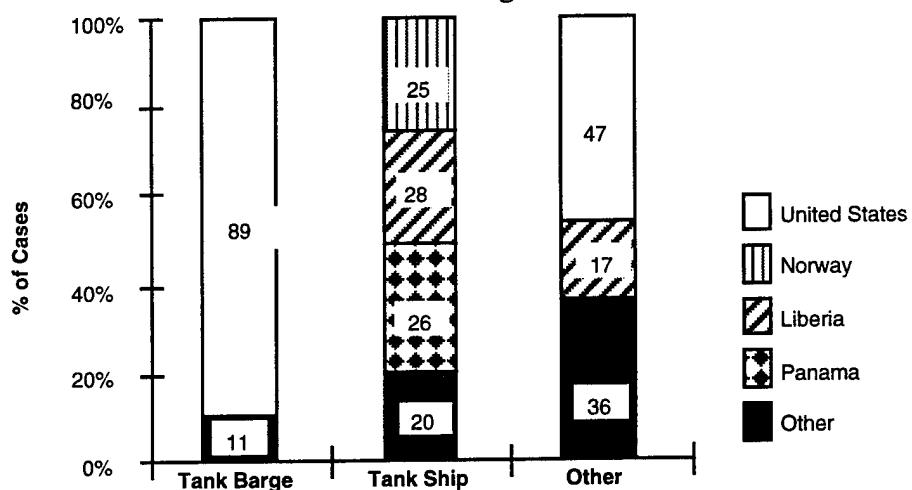
4.1.4 Adverse Weather was Implicated in 7% of the Spills Usually Related to Lost Containers or Emergency Release

In 23 records adverse weather or natural disasters were noted as a cause or contributing factor to a spill. Where weather is a contributor, it usually was related to container vessels or barges losing a container or tank. Undercounting of weather as a cause of spills may be related to that weather is not listed as a potential primary or secondary cause in some data bases for collecting spill information. However, the Study Team's review of the records in the MSO's indicated that the weather was only a factor in one incident not described in either the narrative or as a contributing cause in the Federal data bases.

4.1.5 Spills Generally Occur from US Flagged Tank Barges and Foreign Flagged Tank Ships

The vessel flag and type of service appear to be strongly related. Additional data concerning the total number of vessels using US waters by flag would provide data to understand these frequencies fully. For example, there are comparatively few US flagged tank ships and it follows that there would be few to no significant spills in this category. Conversely, the number of spills that occurred from tank ships with Norwegian, Liberian, and Panamanian flags is roughly the same, but it is unknown if the number of vessels is the same (see Exhibit 3-8).

Exhibit 3-8: Vessel Flag vs Vessel Service



4.1.6 Spills Are Distributed Evenly Over Annual, Monthly, and Daily Periods

The data indicate that the potential for a spill appears to be nearly equivalent regardless of the time period.⁶ This is based on the assumption that cargo transfers and vessel movement is equivalent during these time periods. Further, there does appear to be several potential peaks in the monthly and daily periods, but it is not statistically significant and may be coincidence. Additional information on the number of transfers occurring over specific daily and nightly periods along with vessel traffic during the day and night or each season may lead to a different conclusion. Information obtained from the MSO visits indicated that vessel transfers usually started during the day, but usually took more than 12 or even 24 hours to complete. Also, Captains of the vessels try to arrange that they enter and depart a port during the daylight hours and transfer cargoes at night. This is done because they view it as more dangerous to pilot a ship at night through a port than to transfer cargo at night. Once underway, vessels usually continue moving day and night until the destination is reached. Exhibit 3-9 depicts the number of spills occurring on each day of the week. Exhibit 3-10 depicts the number of spills occurring each month. Exhibit 3-11 depicts the time-of-day each spill occurred.

⁶ The primary national data bases for collecting spill information (ERNS, MSIS, IRIS, and CASMAIN) were all created during the 1980s. The quality of the data and the familiarity with the reporting requirements has been steadily increasing. Consequently, the number of reports has been increasing, but this is probably not a result of increases in the number of spills.

Exhibit 3-9: Day of the Week vs Spill Occurrence

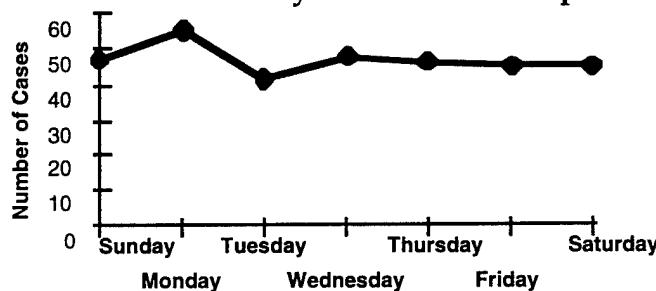


Exhibit 3-10: Month vs Spill Occurrence

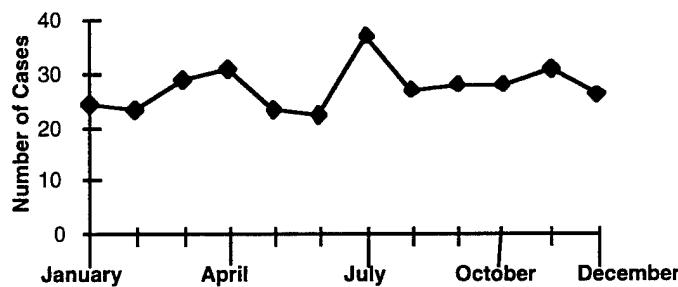
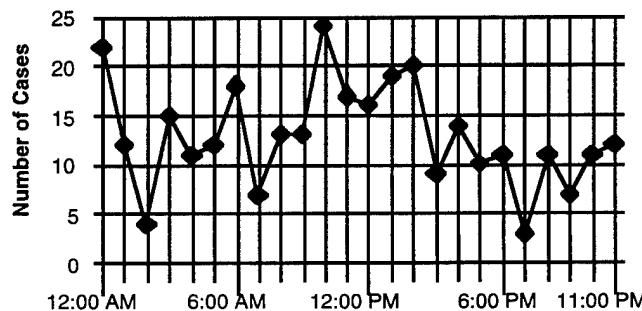


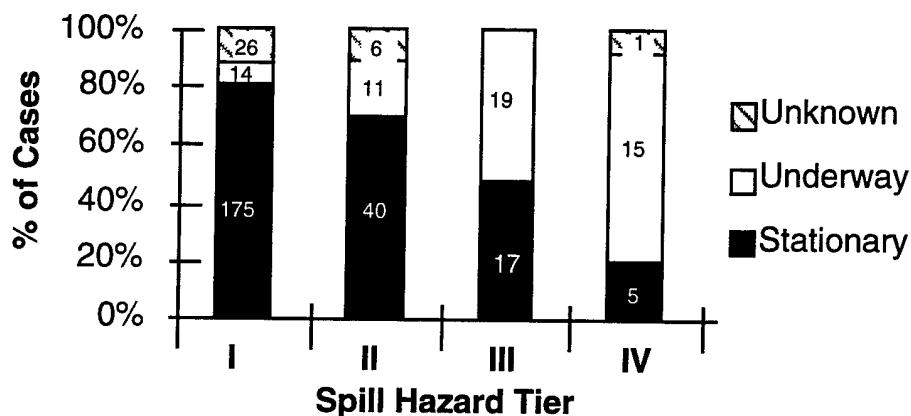
Exhibit 3-11: Time-of-Day vs Spill Occurrence



4.1.7 Vessels that are Stationary Account for 80% of All Spills, but Moving Vessels Account for 75% of the Largest Spills

Vessel movement at the time of a spill was divided into underway or stationary. Stationary vessels are typically involved in the transfer of cargoes. Exhibit 3-12 shows stationary vessels are associated with 81% of Tier I, but a smaller percentage for other tiers.

Exhibit: 3-12: Spill Ranking vs Transportation



4.2 The MORT Model Identifies the Direct and Root Causes of a Spill

The MORT analysis identifies one direct cause for each of the 329 spill incidents. The direct cause is the first level of causes under the vulnerabilities in the MORT model in Exhibit 3-3, which are Human Error, Equipment Failure, Structure Failure, Environment, Other, and Not Provided (insufficient data). The MORT Model also identifies root causes of spills. These root causes are the specific factors described in the MORT Chart.⁷ In a MORT analysis, each direct cause is considered to have a number of root causes that create the chain of events that lead to a spill. Please refer to Appendix D for more information regarding the conceptual fault tree of causes of spills.

4.2.1 Human Error is the Direct Cause of 39% of Spills

The frequency of occurrence of the direct causes of spills is found by analyzing the vulnerabilities in the MORT model. The result is depicted in Exhibit 3-13. This shows that human error is directly responsible for 39% of all spills.

⁷ The complete MORT Model Diagram was provided to USCG under separate cover. Occurrences of these factors are described in the following sections.

Exhibit 3-13: MORT-Based Vulnerabilities (Direct Causes of Spills)

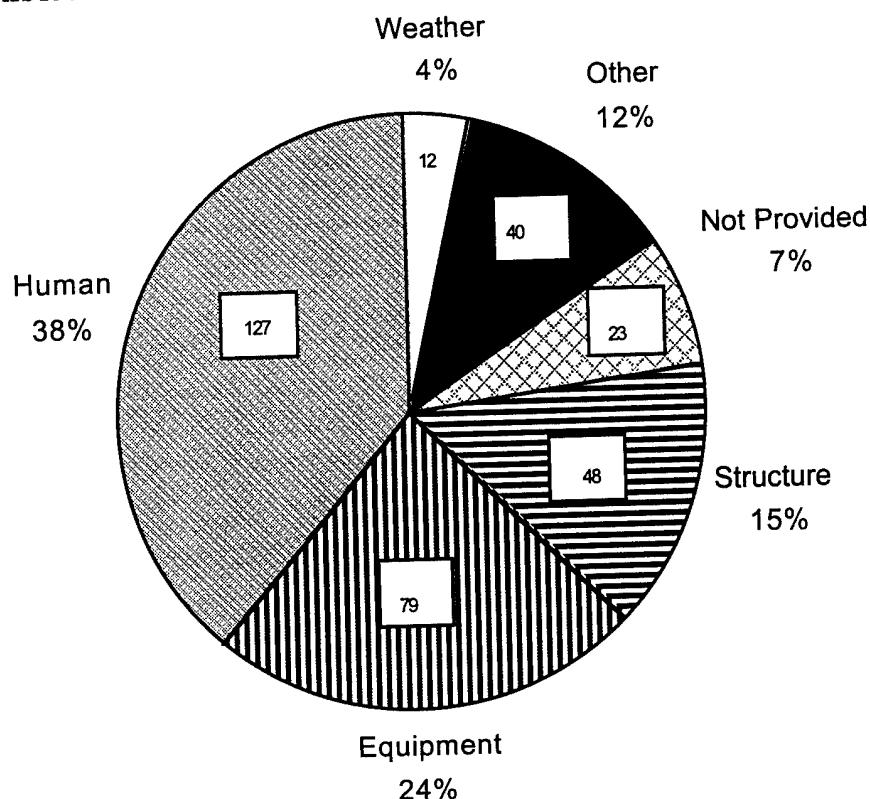


Exhibit 3-14 shows the direct causes and the associated spill hazard tier.

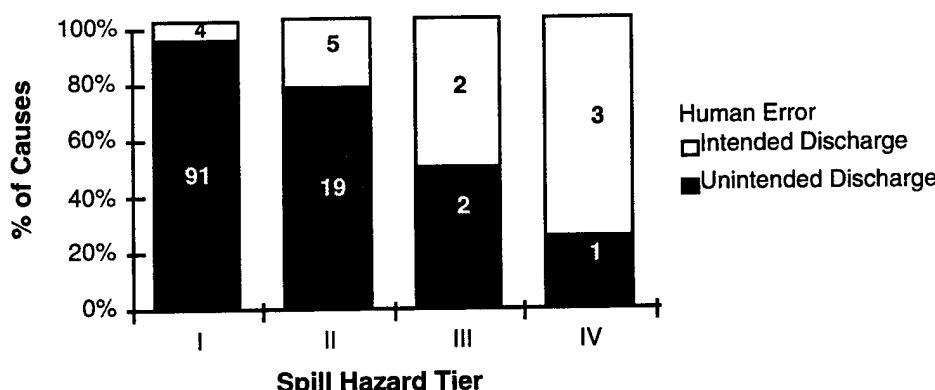
Exhibit 3-14: Direct Cause vs Spill Hazard Tier

Direct Cause	Tier I		Tier II		Tier III		Tier IV	
	# Spills	%	# Spills	%	# Spills	%	# Spills	%
Human	95	44	24	41	4	11	4	18
Equipment	58	27	14	24	6	17	1	5
Structure	17	8	9	16	16	46	6	27
Weather	6	3	2	3	2	6	2	9
Other	23	11	7	12	5	14	5	23
Not Provided	15	7	2	3	2	6	4	18
Total	214	100	58	100	35	100	22	100

Using the data and the MORT model, human vulnerability is considered the most frequent direct cause of spills. Of the 127 human error spills, 75% are Tier I and only 3% are Tier IV (see Exhibit 3-15). Human error was divided into two categories; intentional and unintentional. Intentional errors included causes described as illegal waste discharge and releasing of cargo to ensure safety of the vessel. It should be noted that the information in the data bases did not support

finding human error to be a direct or root cause of spills involving grounding, collision, allision⁸, capsizing, or sinking. This is probably a deficiency in the data bases because pilot or other human error probably lead to these events.

Exhibit 3-15: Spill Ranking vs Human Errors



4.2.2 Root Causes of Spills Identified in the MORT Analysis

The frequency of root causes is determined in the MORT analysis. The root causes are discussed as: human vulnerability; equipment vulnerability; weather vulnerability; physical barriers; administrative controls; and energy flows. This information provides the key underlying factors that lead to the direct causes of spills. Please refer to Appendix E for a listing of all root causes.

4.2.2.1 Root Causes from Human Vulnerabilities are Primarily Associated with Transfer of Chemicals

Human vulnerability root causes of spills are 89% of the time described as unintentional. The three most commonly cited unintentional errors are tank overflows (83 times), inattention (24 times), and unspecified direct human error (45 times). Most of these events are associated with the transfer of bulk liquid chemicals.

4.2.2.2 Equipment Failures are a Root Cause in 179 Spills

Using MORT analysis, equipment vulnerability is the direct cause of 79 spill events. As a root cause, equipment failure or multiple equipment failures is listed 163 times in the chemical incident data base. The most

⁸ An allision is the ramming or other contact of a moving vessel with a non-moving object, such as a pier, bridge, or train tressel.

frequently listed failures are hose ruptures and valve leaks or failures. Exhibit 3-16 depicts the frequency of equipment failures.

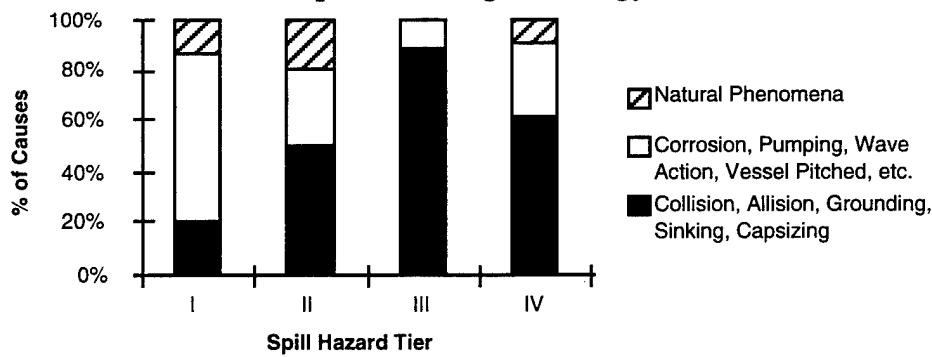
Exhibit 3-16: Spill Ranking vs Equipment Failures

Equipment Failure	Number of Listings	Percent of Failures
Hose Rupture	28	17
Valve Failure/leak	23	14
Container/Package Lost/Failed	18	11
Container, Tank Spill	14	9
Not Elsewhere Classified	11	7
Gasket Failure/leak	11	7
Cut, Severing	10	2
Pipe Rupture	10	2
Other	38	23

4.2.2.3 Collision/Allisions Provide the Energy Flow for Most Larger Spills

The energy flow was described in about 25% of the spills in the chemical incident data base. In general, only energy flows that in some data bases are considered the direct or secondary cause of a spill are described in the data base. This data is congruent with the general premise that collisions, allisions, capsizing, sinking and groundings are more likely to lead to a more serious spill. Other energy flows such as corrosion, power failure, wave action, vessel pitched, and natural phenomena are more likely to lead to Tier I spills, but can lead to larger spills. Exhibit 3-17 shows the result of this analysis.

Exhibit 3-17: Spill Ranking vs Energy Flows



4.2.2.4 Physical Barriers and Administrative Controls are the Key Prevention Activity and Are Inadequate

Barriers and controls can be associated with the prevention aspects of a spill. Physical barriers and technology are installed to prevent spills and personnel are trained to follow procedures that lead to the normal operating conditions of a vessel and its associated operations.

Therefore, if a spill occurs, in general some procedure was violated and

either a physical barrier such as an alarm did not work or was not installed. A review of the MORT model analysis shows that only 14 times was a physical barrier noted as related to a spill, but administrative controls were noted 172 times. Further a review of the details concerning the spills citing physical barriers showed that six of the spills involved shutoff valves that were either damaged by an accident or left open. The Study Team therefore concluded that either physical barriers do not exist or are infrequently used.

Administrative controls are described in the chemical incident data base for procedures conducted primarily while the vessel is stationary. Administrative controls for moving vessels such as using up-to-date navigation charts and pilot errors are not captured in the data. Exhibit 3-18 shows the spill ranking versus administrative control errors. Improper transfer operations is the most common failure that enables a spill to occur. Another important failure is improper securing, which is associated with 29% of Tier III and 50% of Tier IV spills.

Exhibit 3-18 Spill Ranking vs Administrative Control Errors

Administrative Control	Tier I		Tier II		Tier III		Tier IV	
	# Spills	%						
Improper Transfer Operations	38	30	6	18	2	29	0	0
Improper Operations, General	21	17	6	18	1	14	1	25
Improper Valve Operations	19	15	4	12	0	0	0	0
Improper Securing	10	8	5	15	2	29	2	50
Failure to Shutdown	7	6	3	9	0	0	0	0
Improper Maintenance	6	5	2	6	1	14	1	25
Other	26	20	8	24	1	14	0	0

5. The Results of the MORT Analysis Highlights Specific Issues for Future Research and Prevention Efforts

The MORT analysis provided information regarding the frequency of causes of spills and other characteristics of spills. This information can be used to consider methods for preventing future similar spills from occurring.

5.1 The MORT Analysis Indicates that Future Research Should Focus on Prevention of Technical and Human Factors Rather Than Response to Spills

One implication from this analysis is that management focus on specific factors would likely have reduced the incidence of hazardous chemical spills. These specific factors include:

- The elimination of collisions/allisions, over-pumping, and grounding
- Human factors: training, testing, surveillance, engineering controls
- More rigorous equipment maintenance and quality assurance programs for pipes, valves, hoses, and tanks in the Gulf of Mexico Texas-Louisiana Region
- Installation of prevention equipment

Since there are several primary direct causes of spills it appears likely that management control or elimination of the underlying vulnerabilities would have some mitigative effect on the frequency and/or severity of the hazardous chemical spills.

With respect to the "Systemic Management Control Factors" leg of the MORT Chart, existing data on the study sample of spills was inadequate to determine the impacts of management policies on the cause of the spill. In other more in-depth studies on particular spills, these factors frequently are found to be key components of the "root cause" chain of events leading to an accident or spill.

The major areas requiring improved technology and management attention are:

- Data acquisition (e.g., root cause check off entries in inspection reports or improved lists of potential causes in Federal data bases)
- Human factors
 - Training
 - Testing
- Equipment factors
 - Maintenance and quality assurance programs
 - Equipment-based prevention devices

5.2 A Detailed Review of the Root Tree of the MORT Analysis Indicates Several Common Spill Scenarios on Which to Focus Prevention Efforts

Using the MORT analysis, the Study Team developed root trees for four vessel service types. The root trees are for tank barges, tank ships, mobile

offshore drilling platforms, and fixed facilities. These service types were chosen because spills occur more frequently from them, and they represent four very different classes of regulated vessels and facilities. These root trees show that several common spill scenarios are evident. Identification of these common scenarios is similar to a hazards analysis, and provides a micro-level review of the key factors. Hazards analysis is a bottoms-up, narrowly focused, job-task perspective for identifying and controlling specific and unique potential hazards. This is generally done in a proactive manner to prevent accidents from occurring. In this case, retroactive identification of the scenarios provided a basis for identifying areas that need further examination. Exhibits 3-19 through 3-22 examine the vessel service type, transport mode, direct cause and root cause. The root cause is described by listing each root cause and the number of occurrences associated with each direct cause.

Exhibit 3-19 depicts the root tree analysis for tank barges. From this analysis it is evident that tank barges are US flagged. If a tank barge is involved in a spill, then 70% of the time it is stationary, and 20% of the time it is underway (10% is unknown). If the barge is stationary, then 50% of the time the accident is caused by human error predominantly involving transfer of bulk liquids. Equipment failure is the direct cause 25% of the time, and these failures also usually involve transfers of bulk liquids. For barges that are involved in accidents while underway, the direct cause is almost always involving a collision, allision, or grounding leading to a ruptured hull or tank.

Exhibit 3-20 depicts the root tree analysis for tank ships. From this analysis it is evident that tank ships involved in accidents are almost always foreign flagged. The most common occurrence is with Liberia at 36% followed by Panama and Norway with 20% each. Spills involving tank ships occur more than 80% of the time when the ship is stationary. Approximately 70% of these spills involve human error as the direct cause. Almost all spills from tank ships regardless of the direct cause involve the operations and equipment for conducting transfers of bulk liquids.

Exhibit 3-21 depicts the root tree analysis for mobile offshore drilling platforms. Spills from these facilities occur when they are stationary and involve human or equipment errors. The root causes include improper procedures for using valves and hoses or leaks in valves, pipes, and ancillary equipment.

Exhibit 3-22 depicts the fixed facility root tree analysis. Equipment failure is the direct cause in 70% of these incidents. The root causes associated with equipment failure are flange, gasket, and pipe leaks or failures. Other characteristics from the MORT analysis that apply to the common scenarios is that spills are more prevalent from the lower Mississippi river

system through the gulf coast and to the Houston area. Spills do not appear to occur more frequently in any season or time of day, and the material being transported does not appear to be a factor in causing spills.

The size of the spill is a factor of the cause of a spill. While Tier III and IV spills comprise 18% of the data base, these larger spills are usually the result of a collision or allision. Smaller spills generally occur as a result of human errors or equipment failures during transfer of bulk liquids operations.

The Study Team also noted three other less common spill scenarios:

- Unknown/undiscovered leakage from a tank during a several-day period, particularly from single-walled barges, resulting in small to medium size spills.
- Wave action washing containers overboard or unbalancing containers causing human intervention to release the containers to save the vessel.
- Excessive wear or cutting of seismic cables in the gulf of Mexico resulting in releases of Isopar M.

As noted above, several common scenarios capture almost all causes of spills. Although most spills are small, the potential exists for a large spill. There are several examples in the data base where a 1,000 gallon spill occurred but the tank or container capacity was for 500,000 or more gallons. Future research and development efforts should be focused on these common scenarios.

Exhibit 3-19: Tank Barge Root Tree

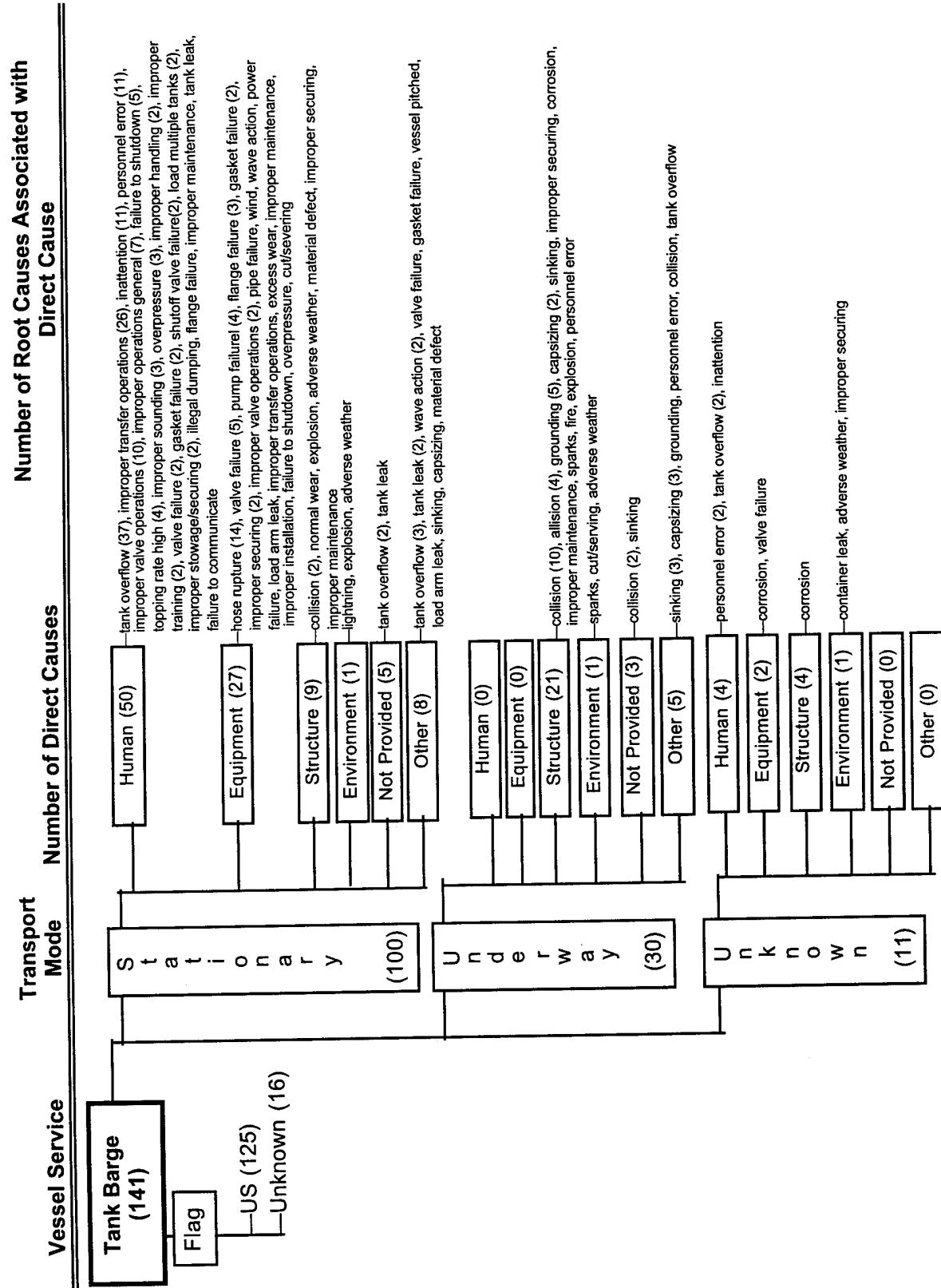


Exhibit 3-20: Tank Ship Root Tree

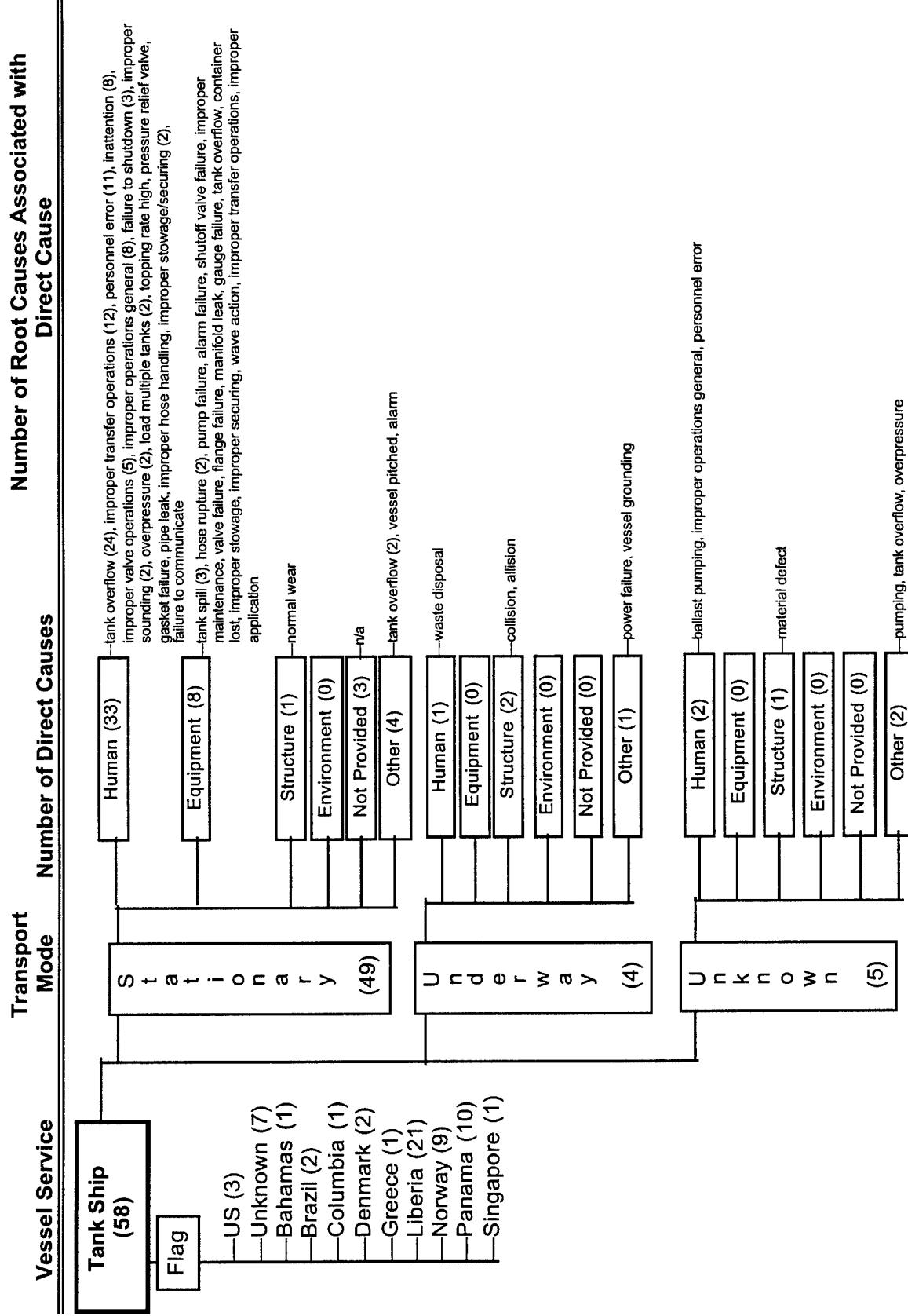


Exhibit 3-21: Mobile Offshore Drilling Platform Root Tree

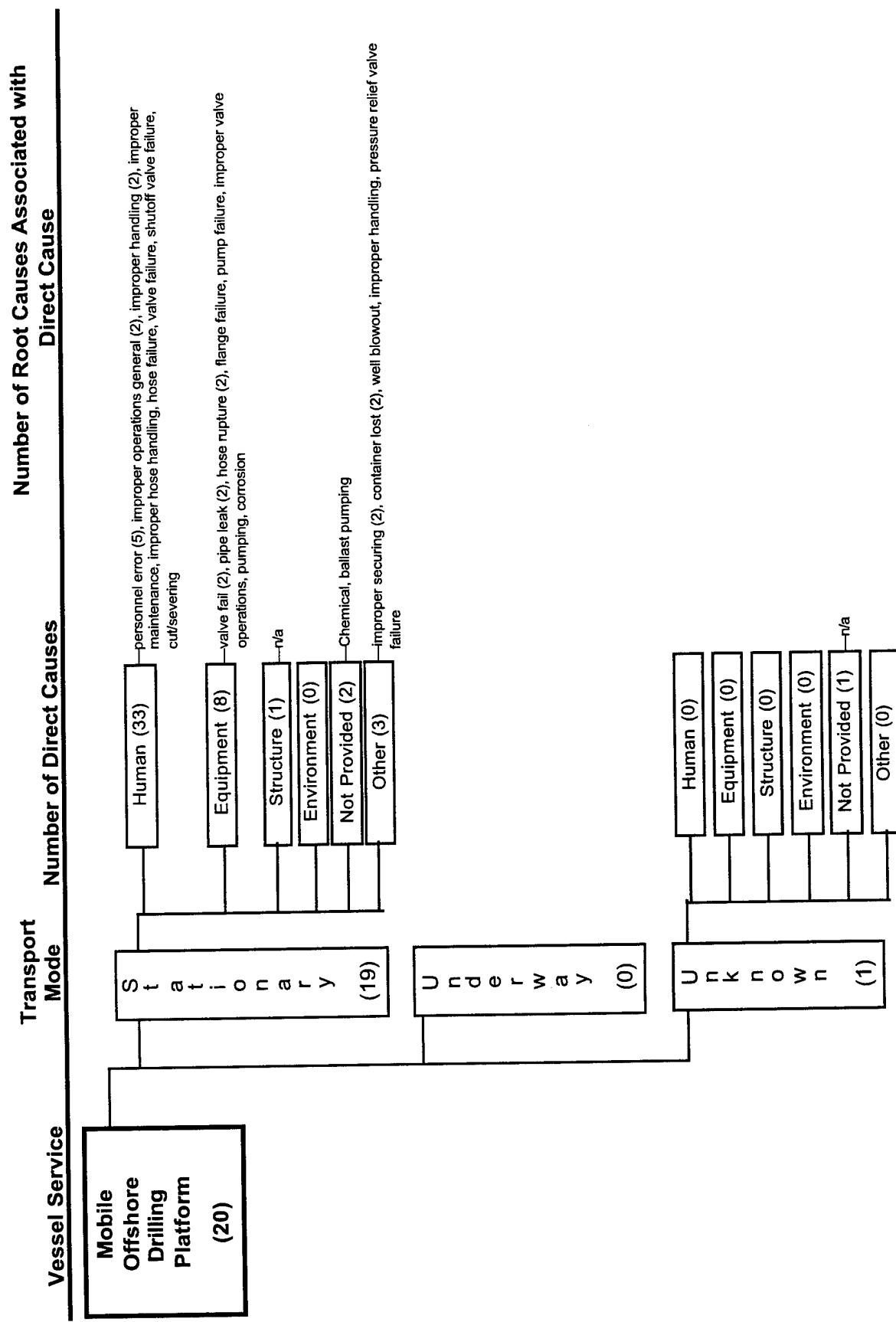
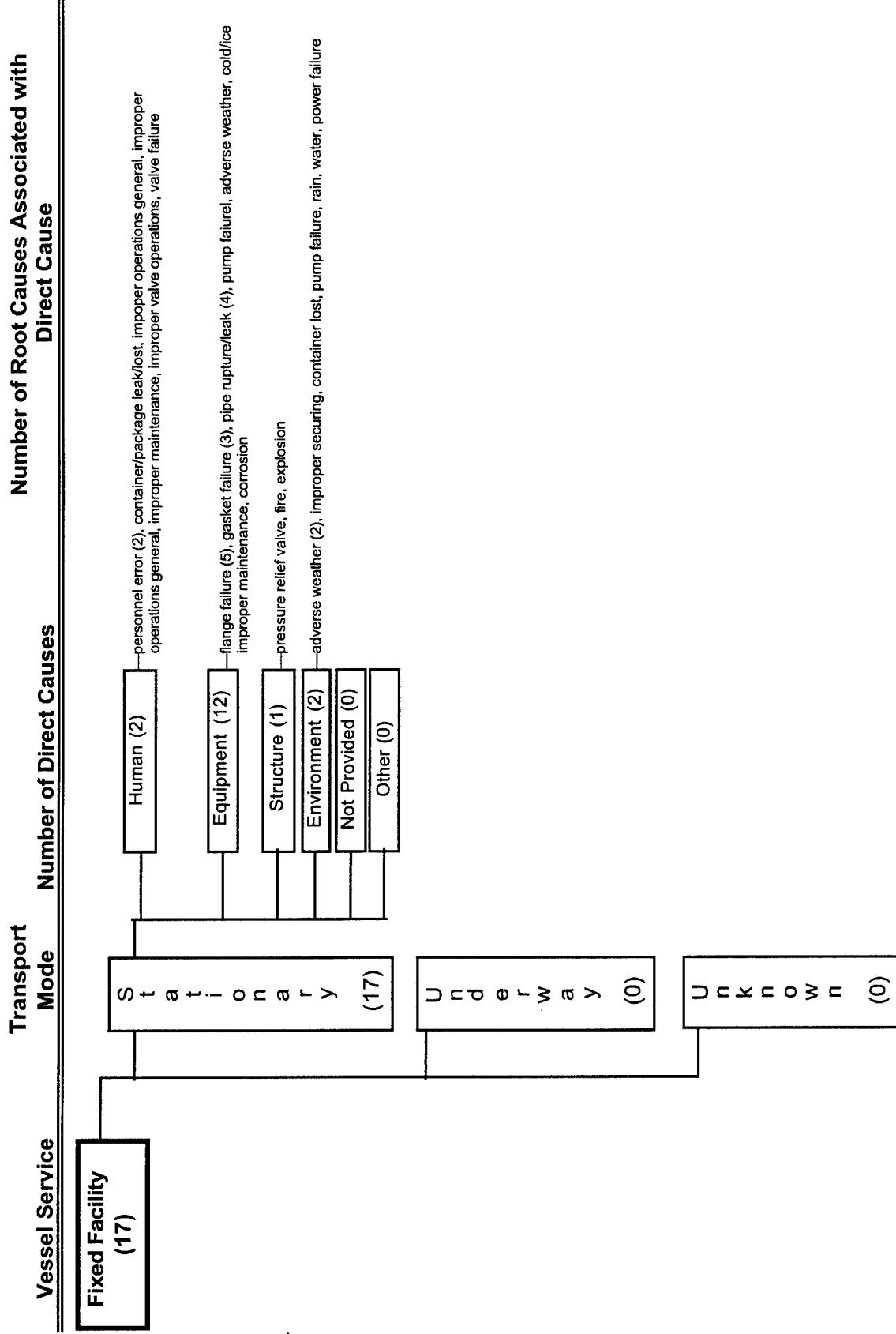


Exhibit 3-22: Fixed Facility Root Tree



Chapter IV: Conclusions And Recommendations

The MORT model analysis provides the overall results and conclusions from the study. These results and conclusions are the basis for the Study Team's recommendations, which are presented in the latter section of this Chapter.

1. This Study Provides Information About the Numbers, Causes, Sizes, and Other Information Regarding Spills for Future Prevention Efforts

In this Chapter, results and conclusions are grouped into four categories: 1) general, 2) spill causes, 3) spill prevention, and 4) information sources.

General Results

- During the last ten years, 329 significant hazardous material spills occurred in the United States.
- Baseline data on number or causes of spills prior to the development of existing data bases or regulations do not exist.
- 55% of the spills in this study range from 100-350 gallons; 95% of spills reported in the data bases are less than 100 gallons.
- 90% of the spills are reported in the Gulf of Mexico, Mississippi River system, and Eastern seaboard, which are areas of high cargo handling activity; few spills are reported from ports on the Pacific Ocean and Great Lakes.
- About 6% of all US waterborne commerce contains chemical products, which is approximately 126,000,000 tons per year. The total of lost chemical products from spills each year on average is less than 2,000 tons or <0.001%.
- Ten spills, or about 3%, involved evacuations, injuries, or deaths; and 21 spills involved releases of more than 100,000 gallons.
- Many of the busiest ports in the US are near large populations, such as New York City and northern New Jersey, Houston, and New Orleans, which creates a larger potential hazard from chemical spills.

General Conclusion

- The occurrence of chemical spills may be relatively low because: 1) facility awareness of high hazard potential; 2) USCG inspections and regulations; 3) current prevention equipment; and 4) operating procedures at plants.

Results Regarding Spill Causes

- Most spills can be categorized into several spill accident event trees. Of these, almost all spills are caused by operator-related errors involving vessel transfer operations. The major causes of spills are:
 - Inattention involving vessel transfer operations;
 - Hose, pipe, gasket related problems usually caused by human error;
 - Unknown causes of holes or cracks in tanks;
 - Collisions and allisions;
 - Wave action on moorings or containers on board.
- Factors that are highly characteristic of a spill include: US tank barge (inland waterways) moored to a dock; non-US tank ship (docks and coastal areas), transfer of bulk liquids, primary equipment failure such as valves, hoses, pipes, and tank/container leak not prevented by human prevention controls; and operating in Texas.
- Factors that are less likely to characterize spills include: adverse weather; time of day; failure of physical prevention barriers such as alarms and pressure relief valves; and material being transferred/shipped.
- Most spills involve transfer operations to or from a stationary vessel and result in Tier I or II spills. Tier III and IV spills usually involve one or more moving vessels.
- There are few collisions or allisions involving vessels transporting chemicals.
- Detailed data on the chain of events that cause a spill are generally not available, such as management system factors which include policies, procedures, and attitudes.

Conclusions Regarding Spill Causes

- Most spills involve human error in operating either vessel or fixed facility equipment.
- Operating procedures have a significant impact on the likelihood of a spill occurring.
- Technology that would prevent common human errors during transfer or navigation would reduce the number of spills.

Results Regarding Spill Prevention

- Consistent reductions of penalties below recommended levels are noted by industry and may be reflected in their prevention activities.
- Following current USCG regulations generally will prevent spills.
- Industry and State concerns and attitudes regarding operations greatly influence the likelihood of spills.

Conclusions Regarding Spill Prevention

- USCG inspections and penalty policies appear to impact the operating procedures at chemical plants and on-board vessels.
- Efforts to increase communication to industry, States, and professional organizations regarding the potential consequences of spills and the techniques for preventing spills may shift their attitudes and increase their emphasis on prevention.

Results Regarding Data

- All marine spills that occur are entered into MSIS.
- The data entry choices in MSIS for categories, such as causes of spills, are inadequate and do not reflect the potential causes of spills.
- MSIS does not have a data dictionary, thus different data entry operators may categorize similar events differently.
- Data on vessel traffic and number of transfers are critical for comparing spill rates between ports, but do not exist.
- MSOs maintain closed inspection and penalty records for up-to three years, then the records are sent to archives. The records are destroyed seven years after the cases are closed.

Conclusions Regarding Data

- Despite data limitations, the data demonstrates the most likely direct causes of spills and that human factors in operating the equipment are at the root of most spill events.
- Since USCG inspection, preparedness, and response units do not monitor the daily activities concerning transport or transfer of hazardous materials, inspections may not be appropriately targeted and the units may not be adequately prepared for a low probability but high consequence spill.

- Since records of vessel traffic and transfers are not maintained, it is difficult to establish the effectiveness of new, current, or past inspection, regulatory, or research programs.

2. Recommendations from this Study Emphasize Prevention, Focusing On Scenarios that Characterize Common Spills

As described in the **Summary of Hazardous Chemical Spill Response Projects**, past research efforts focused on spill response planning and implementation. The projects generally focused on:

- Modeling behavior of released substances
- Rapid analysis of substances
- Detection and tracking of spills
- Treating and containing releases
- Personal protection equipment
- Disposal

The resulting equipment, technologies, and information from these studies are being used today by the National Strike Teams and the response planning community. As a result, the emphasis for future research and development efforts should focus on prevention.

The Study Team's recommendations are divided into three categories: 1) spill prevention; 2) information systems and information distribution; and 3) inspection operations and procedures. Each of these categories has implications for research and development, and most have potential implications for regulatory development and current operations. Research and development is necessary to investigate potential technologies and methods for accomplishing each recommendation. In some cases changes can be made to current operations based on the results of the research; however, in other cases regulatory changes may have to be made to implement the results of research and development efforts. Current operations should change to incorporate the results of these analysis or regulatory changes.

2.1 Spill Prevention Research Should Focus on Two Areas: Human Factors Analysis and Improvement to Equipment

Human factors analysis focuses on eliminating the contributing causes and barriers to spills, whereas equipment factors are usually the direct causes of spills. In some cases improvements can be made to both the equipment and human interface with the equipment. An example is improving overflow alarms to enable alarms to more accurately reflect the level of the liquid and improve/increase the operator reliance on the alarm versus visual observation.

2.1.1 Conduct Human Factors Analyses

Human controlled operations have become increasingly important with the increasing complexity and speed of technology. Personnel are relied upon for prevention actions (e.g., proper inspection and testing of equipment), operations (e.g., navigating safely through US waterways), and for response actions during abnormal and emergency operations. To enable improvements in human controlled operations, analyses would focus on human behavior, abilities, limitations, and other characteristics to design tools, systems, and tasks that are more productive, safe, and effective. These analyses would seek to uncover the reasons that human error due to inattention or improper procedures occurs on vessels and facilities. This would be done through case studies using the spills reported in the chemical incident data base or onsite visits and inspections. This research may focus on:

- Controls - gauges, alarms, layout of controls
- Work environment - warning signs, placarding, physical comfort, noise, temperature
- Staffing - minimum needs, overtime, training, communication of risk
- Instrumentation - sufficient, timely, reliable, understandable

2.1.2 Change or Develop New Equipment

Failed or inadequate equipment is a major direct cause of spills that can be eliminated through changes to equipment and or new technologies. A major root cause is the lack of adequate prevention equipment or technologies. Examples of these equipment or new technologies include:

- **Vapor recovery systems and closed system requirements** - Similar requirements are already required for certain applications such as pesticide transfer from fixed facilities to trucks in the State of California. Development of cost effective technology useable in the marine environment should aim to prevent minor spills from transfer operations. This is related to the major causes of spills in the chemical incident data base.
- **Improved alarms** - This should reduce the number of spills caused by topping off tanks.
- **Improved pressure relief valves** - On many barges, the pressure relief valve is essentially a ball in a pipe that is floated out when the tank is overfilled. Alternate technologies can be designed or implemented to recover lost product.

- **Hose engagement gaskets** - Currently it is possible to disconnect transfer lines before they are fully purged which generally results in Tier 1 spills. Alternate hose connection devices could be developed that would prohibit the disconnection of hoses before the line is purged.

2.2 Targeted Analysis of Certain Spills Would Improve Knowledge

2.2.1 Conduct Case Studies of Common Spill Scenarios

Several common spill scenarios were identified in this analysis that characterize most spills. Several case studies of recent spills would provide in-depth information regarding the equipment, human, regulatory, and management factors characterizing these spills. These case-studies should fill-in the data gaps concerning almost all spills.

2.2.2 Conduct Case Studies on Specific Factors

Several specific factors such as materials appear to characterize larger spills. An in-depth analysis of the procedures surrounding commonly spilled materials versus materials rarely spilled may provide insights into the causes of these spills.

2.2 Information Systems Should be Improved

2.2.1 Develop a MSIS Data Dictionary

The dictionary would describe the purpose of each field and standard entry into the MSIS data base. This would improve consistency of information between data entry personnel and between MSOs. The data dictionary would be used as a reference for training new personnel in the system along with providing a standard reference for describing the data.

2.2.2 Revise Choices in MSIS for Causes of Spills

This would improve future data collection efforts by providing more accurate data on causes of spills. The potential choices for spill causes would more accurately reflect direct and root causes. Using the information from the chemical incident data base and MORT analysis to delete and add potential causes to the standard selection list would ensure that the list more accurately reflects the causes of spills.

2.3 Information Distribution Needs Include Tracking Hazardous Material Handling Activities More Closely and Coordinating Information Needs and Uses

2.3.1 *Maintain Vessel Traffic Statistics*

This would seek to establish data on the number of vessels hauling chemical products in order to understand the potential for spills, particularly high consequence spills. Current models rely on extrapolations and generalizations regarding vessel traffic. This would also greatly enhance the efforts of response and contingency planners to plan for most likely and worst case scenarios. Traffic statistics would also improve the understanding of the magnitude of the potential for spills. This could be implemented by improved internal interface with other USCG branches that may collect this data. For example, in a few MSOs, this data is required to be collected by the Captain of the Port, but is not transmitted to MEP. The Research and Development Center should also consider harnessing the new or enhancing the new technology that is proposed for Vessel Traffic System (VTS) 2000 to automatically capture traffic data. Pilot projects to collect this information should be implemented.

2.3.2 *Obtain and Maintain Data on Transfers of Substances*

Since most spills are associated with transfers of bulk liquids, this data would provide several benefits. First, inspectors could target inspections of transfers. Second, response and contingency planners would be alerted to the increased potential of a spill. Data on the frequency of spills during transfers would be vastly improved. This could be implemented by requirements from the Captain of the Port or a regulatory change.

2.3.3 *Develop an Industry Best Practices Manual*

The level of technology and common practices varies greatly between facilities. Proprietary information also reduces the ability of vessel operators and facility managers to share ideas and techniques for preventing spills. The Research and Development Center should develop guidance on the best industry practices for preventing spills such as a best practices manual for conducting bulk liquid chemical transfers. The manual would discuss equipment, training, operations, and facility design.

2.4 Targeting Inspections and Consistent Application of the Penalty Policy Would Reduce Spills and Conserve Resources

2.4.1 Analyze Use and Application of Penalty Policy

This analysis would seek to establish a correlation between the number and size of spills and MSO or District application of the penalty policy to either change the penalty policy or enhance compliance with the policy by MSOs and Districts. Records of violations from port and vessel inspections would be compared with the penalty policy and proposed penalty by the MSO and district. The results of this analysis for selected ports would be compared with the history of spills and vessel traffic.

2.4.2 Develop a System to Target Inspections

This system would optimize USCG inspection resources by focusing on facilities or vessels most likely to be in violation of current regulations. Using data regarding the number of inspectors, facilities, vessel traffic, and spill histories a model would be developed focusing inspections on most likely offenders but maintaining some random inspections. This model would be updated with MSIS data and specific MSO data.

2.4.3 Develop Government Performance and Results Act of 1993 (GPRA) Performance Measures Focused on Prevention

Performance measures for the field could be designed to increase prevention activities and decrease “bean counting.” Current methods for analysis of performance would be reviewed and compared with spill and vessel traffic trends.

References

An Assessment of the Risk of Transporting Gasoline by Truck, DOE; Battelle PNL, PNL-2133, 1978.

Hazardous Material Spills: A Documentation and Analysis of Historical Data, US Environmental Protection Agency, NTIS PB-281 090, 1978.

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MORT User's Manual for use with the Management Oversight and Risk Tree Analytical Logic Diagram, (DOE 76-45/4 SSDC-4, Revision 3) February 1992.

Report on the Maritime Transport of Hazardous and Noxious Substances, USCG; NTIS.

Root Cause Analysis of Performance Indicators, DOE; SSDC, WP-21, April 1989.

Summary of Hazardous Chemical Spill Response Projects, USCG; NTIS 1992.

Summary of Marine Hazardous Chemical Spill Response Efforts 1973-1992, USCG, December 1992.

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Appendix A

Review of Federal Data Base Causal Information

Data Bases Identify the Primary and Secondary Causes of Spills

Each data base identifies the primary and secondary causes of a spill, and the CASMAIN data base identifies other contributing causes. This information provides the direct and some of the root causes for each spill. Although the data bases have standard lists of primary, secondary, and contributing causes, the list for each data base is different. To compensate, the Study Team created a revised list of primary and secondary causes. The Study Team then reviewed the information for each spill and categorized the information into the standardized list of primary and secondary causes. The additional information regarding the spill that was identified during the MSO visits assisted in the categorization of the information.

- **Primary Causes**

ERNS, IRIS, MSIS, and CASMAIN assign primary causes to spills. The frequency of these primary causes is depicted in Exhibit A-1. Equipment failure and unintended discharge are associated with about 60% of all spills. The meaning of unintended discharge is unclear in the data base, but intended discharge appears to mean deliberate human actions. Therefore, unintended discharge may be used as a surrogate for human error. In other cases, it was clear that the "other" category included human error. Therefore, from this distribution human error appears to account for at least 40% of all spills.

Exhibit A-1: Primary Cause Distribution

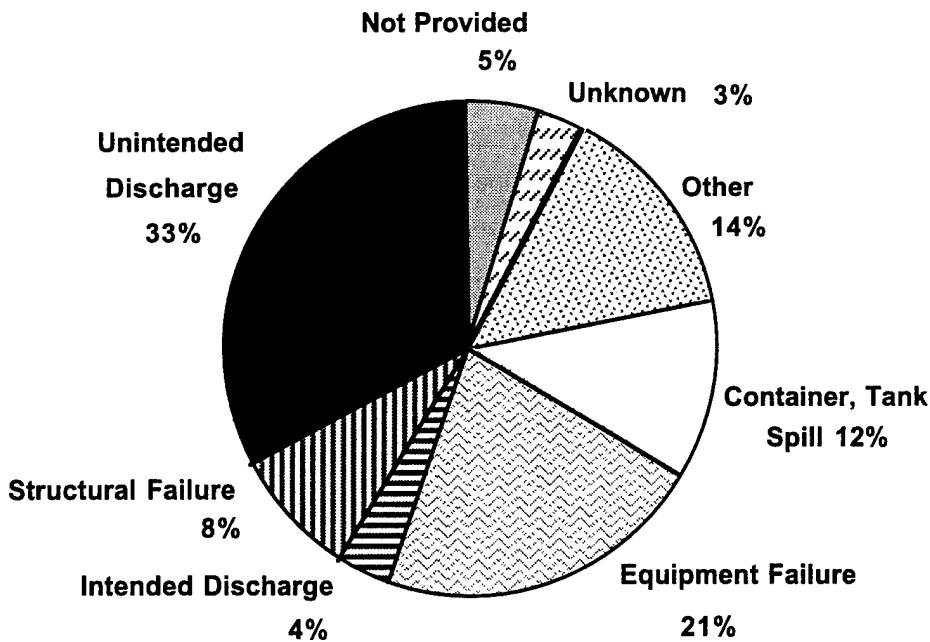


Exhibit A-2 compares primary cause with spill ranking. Unintended discharge and structural failure are associated with about half of Tiers III and IV spills.

Exhibit A-2: Spill Ranking vs Primary Cause

Primary Cause	Tier I	Tier II	Tier III	Tier IV
Unintended Discharge	81	15	10	1
Intended Discharge	4	5	2	2
Structural Failure	11	8	6	2
Equipment Failure	53	11	5	1
Container, Tank Spill	25	12	3	0
Not Provided	8	1	0	9
Other	27	5	9	5
Unknown	5	1	0	2

- **Secondary Causes**

Standard secondary causes are also described in some data bases. These standard causes do not include an option for human error, but they include equipment, structural, and certain procedural errors. Exhibit A-3 depicts the frequency of secondary causes. From this data, it appears that transfer equipment and operations are associated with almost 50% of all spills.

Exhibit A-3: Secondary Cause Distribution

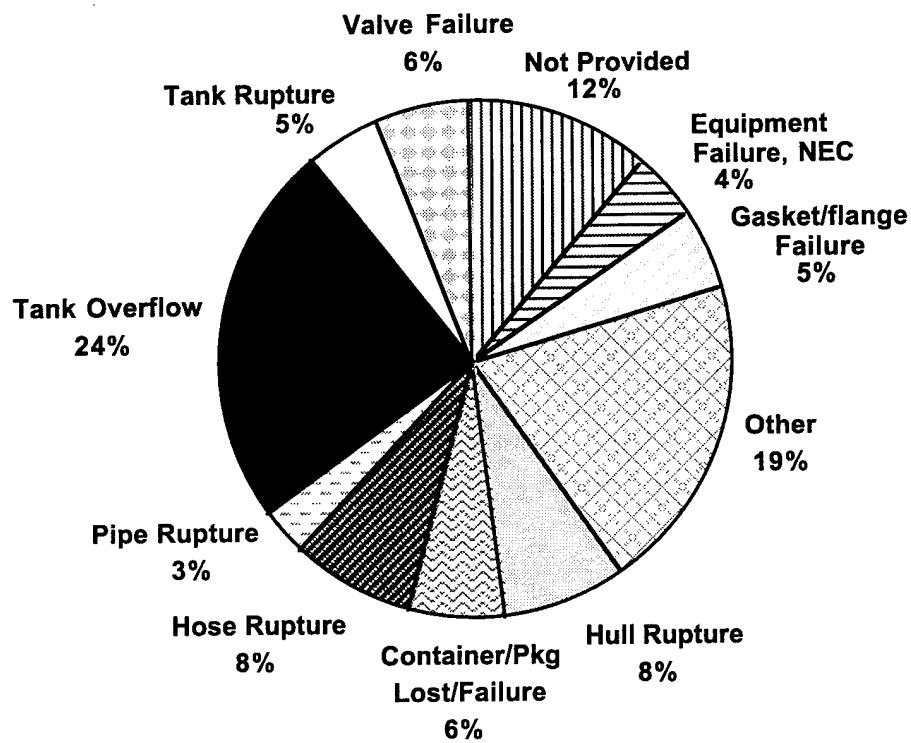


Exhibit A-4 shows that hull rupture and lost containers¹ are associated with 66% of Tier IV spills. Tank and hull ruptures are associated with 45% of Tier III spills.

Exhibit A-4: Secondary Causes vs Spill Ranking

Secondary Cause	Tier I	Tier II	Tier III	Tier IV
Ballast Bilge Pumping	0	1	2	0
COE-EPA Permit Release	1	0	0	0
Container/Pkg Lost/Failure	10	5	3	1
Emergency Discharge	0	1	0	0
Equipment Failure	10	0	2	0
Flange Failure	8	0	0	0
Gasket Failure	6	2	0	0
Hose Rupture	19	4	3	0
Hull Rupture	9	6	10	3
Load Arm Rupture	1	1	0	0
Not Provided	21	4	2	12
Other	29	5	0	1
Overturned Vessel	1	0	3	2
Pipe Rupture	6	2	2	0
Pump Failure	4	1	0	1
Structural Failure	1	0	0	0
Tank Overflow	63	16	4	0
Tank Rupture	7	4	3	0
Valve Failure	16	4	0	0
Waste Disposal	2	2	1	2
Well Blow-out	0	0	1	0

¹ The lost containers category includes barrels, tanks, and containers that are lost overboard, intentionally or unintentionally, generally as a result of weather conditions affecting the vessel. Since control of the cargo is lost, they are considered spills in the spill data bases and for the purposes of this study.

Appendix B

Statistical Analysis Issue

During the course of the analyses, one major issue arose concerning the statistical analysis of the data. Currently, the report lists the frequencies of spill event occurrences. A more detailed analysis not covered in this report involves two related issues. The first issue concerns the availability of vessel traffic data and the second issue concerns the selection of the statistical theorem to use for the analysis. Any statistical analysis requires two key pieces of data. The first is how many opportunities for the event exist, and the second is how many times does the event occur.

Vessel traffic data is a major issue in this case. Based on the available data, we know how many times spills occur when vessels are either stationary, stationary and transferring cargoes, or underway. We do not know how many transfers actually occur over a specified timeframe or the number of vessel miles traveled annually. This means that this data must be estimated or even guessed.

The other issue is which statistical theorem to use to determine projected frequencies of events that occur only once in several thousand or tens of thousands chances. To conduct a component failure analysis normally the binomial theorem is used. However, for instances where the possibility of the event occurring is so low, the binomial theorem cannot be used. In this case the Poisson theorem is used.

An educated guess regarding traffic data can be made based on conversations with USCG personnel and facility data. This data indicates that a barge transfer spill occurs once every 8,000 transfers. Assuming that this is relatively accurate, a port must have at least 40,000 transfers for the analysis to be statistically valid. Nationally this would be valid, because of the large number of transfers at some of our largest ports, but for the other ports, this assumption would be invalid.

Due to the small numbers of occurrences this estimate only works for the initial level of causes of spills. For example, it may work for vessel type and transferring/stationary operations versus underway operations. This level of information serves to assist in characterizing the spill, the next level of data concerns the causes of spills. The next level is human, equipment, environment, and structure. In a few cases estimates can be made at this level, but it does not work for more detailed analysis of causes starting with what type of human or equipment failure occurred.

There were several options for pursuing the statistical analysis in this report. Three are discussed below. Each of these options requires several large assumptions related to estimating numbers of transfers of cargo and vessel miles.

Option 1: Use Frequencies

The analysis is based on assuming that vessel traffic and other items will be the same in the future and that therefore 329 spills would occur over the same time period in the future. It shows general trends and characterizes the causes of spills. It does not provide data that are statistically valid for modeling the causes of spills in the future with varying traffic data.

Option 2: Use Frequencies and Show Event Tree Matrix

This uses the current analysis of frequencies, but expands upon it by showing event trees and frequencies of the events. This would serve to more fully characterize causes of spill, but this data would not be statistically valid.

Options 3: Describe the Issues and Show Only Statistically Valid Modeled Data

This would serve to increase the confidence that the data and results presented are likely to occur in a similar pattern in the future. Unfortunately this data would only be at a very 'cursory' level.

As stated in the beginning of this section, this report lists the frequencies of spill event occurrences, which is option 2. Although, it makes several assumptions, we believe the assumptions to be reasonable and the trends, data, and event trees presented to be reasonably accurate.

Appendix C

Comparison with Other Studies

The Study Team Compared the Results with the Results from Two Other Studies

Two independent studies were evaluated, and the results were compared with those of this study. These two independent studies were:

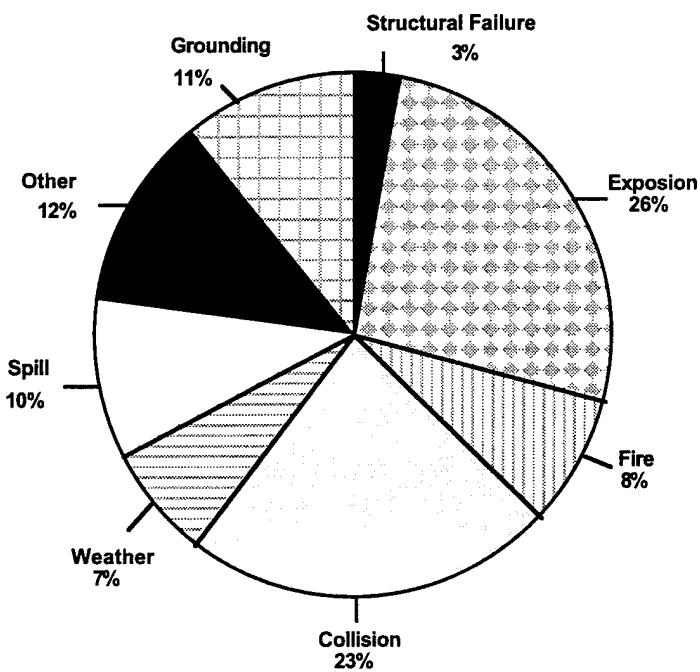
- **Report on the Maritime Transport of Hazardous and Noxious Substances; and**
- **"The Human Element in Marine Safety," *Surveyor*, June 1994.**

Although these studies are not directly comparable because they include oil spills and spills outside of the US waterways, they provide a baseline from which to compare the results of the MORT analysis. The results of each study are described below, followed by a comparison with the results from this study.

- **The Comparison Studies Concluded Human Error to be a Highly Common Cause of Chemical Spills**

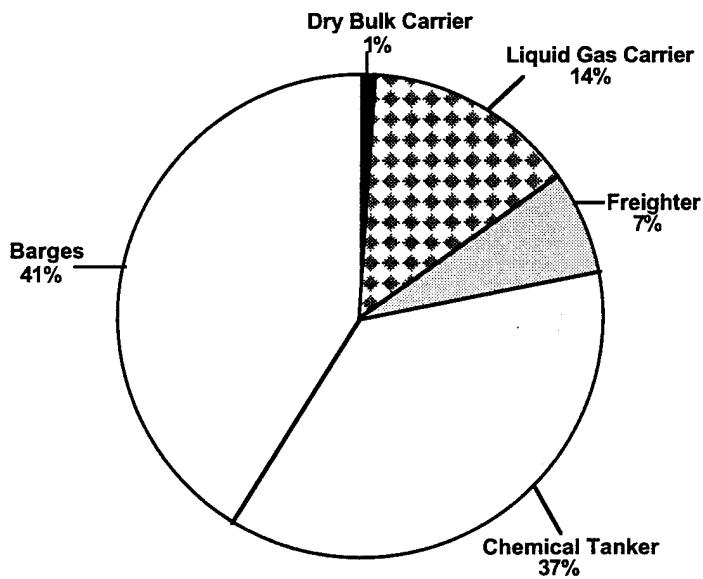
The Report on the Maritime Transport of Hazardous and Noxious Substances captured spill data from around the world and included some oil and petroleum products. The report provided an analysis of the primary causes of spills (see Exhibit C-1).

Exhibit C-1: Primary Causes of Spills
(from the Report on the Maritime Transport of Hazardous and Noxious Substances)



The study also analyzed the types of vessels involved in marine-related spills, see Exhibit C-2.

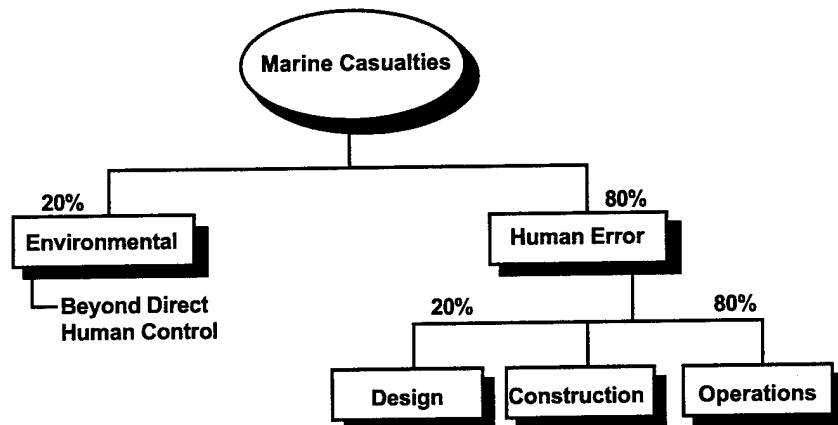
Exhibit C-2: Vessel Types vs Marine Related Spills
(from the Report on the Maritime Transport of Hazardous and Noxious Substances)



The article, "The Human Element in Marine Safety," depicted an analysis of the causes of spills of oil and chemical substances from vessels and offshore oil

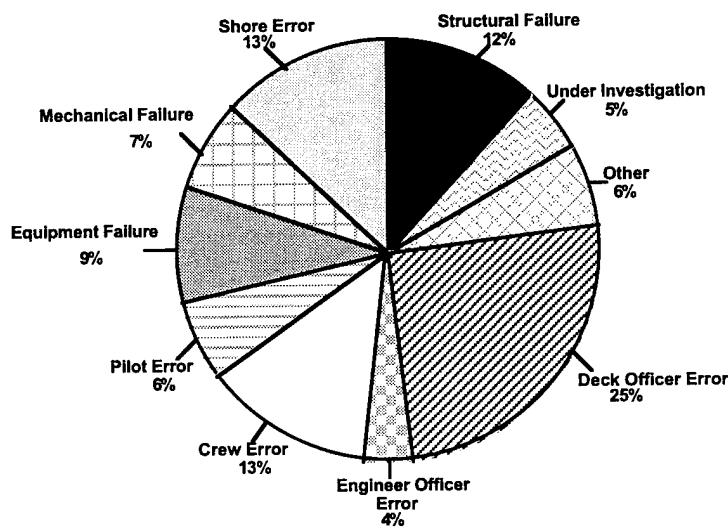
platforms based on insurance claims data. This analysis constructed a basic logic diagram describing the first level of direct and root causes of spills. Using this analysis, human error was concluded to be the root source of 80% of high consequence marine accidents. Considering the human error category, it was further classified that 80% of the errors are in the operations of the systems and only 20% in the design and construction. This analysis was based on human factors causing 80% of all spills. This diagram is presented in Exhibit C-3.

**Exhibit C-3: Diagram of Causes of Marine Accidents
(from *Surveyor*, June 1994)**



This article also presents the frequency of the main causes of marine casualty claims based on a 1993 analysis of the UK P&I Club, see Exhibit C-4.

**Exhibit C-4: Main Causes of Marine Casualty Claims
(from *Surveyor*, June 1994)**



- **Similarities Exist Between this and Other Studies**

Although the spills represented in these two studies do not exactly match the scope of this study, there are a number of similarities between the studies. Exhibits C-1, C-3, and C-4 demonstrate that there are multiple ways to classify causes of spills. For example, only one primary cause is listed as a cause in both of the other studies.

The **Report on the Maritime Transport of Hazardous and Noxious Substances** characterizes the cause of spills into eight categories. The article in *Surveyor*, “**The Human Element in Marine Safety**,” lists ten main causes, but one category is for causes still under investigation. In both analyses, structural failure is listed as a primary cause. It is described as the cause of 3% in the **Report on the Maritime Transport of Hazardous and Noxious Substances** and 12% in “**The Human Element in Marine Safety**.”

The categories in these two studies compare with the MORT model in this report which has five direct cause categories, four subcategories, and numerous root causal factors. The five direct cause categories: human error, equipment failure, structural failure, environment, and other are equivalent to the nine categories in “**The Human Element in Marine Safety**.” This article also contains a diagram of the causes leading to a spill. This diagram depicts that 80% of accidents involve a human element, 80% of which can be attributed to the human error in operations. This compares with the MORT analysis which shows almost all spills involve some human element either through an operational error or prevention, maintenance, and control error.

The **Report on the Maritime Transport of Hazardous and Noxious Substances** also determined the types of vessels that were involved with marine-related spills. By comparing the data in Exhibit 3-6 with Exhibit C-2, barges were found to be involved in a roughly equivalent percentage of spills (40-45%). Tank ships are found to be involved in a large percentage of spills, but less than in the **Report on the Maritime Transport of Hazardous and Noxious Substances** (18% vs 37%). The major difference is that liquid gas carrier accounted for 14% of spills in the **Report on the Maritime Transport of Hazardous and Noxious Substances**, but 0% in this report. However, the vessel choices in the Federal reporting data bases (i.e., ERNS, IRIS, MSIS) do not include liquid gas carrier. This study also includes 60 spills from unclassified vessels and 17 from fixed facilities. Differences between these analyses can be attributed to the fact that this report focuses on U.S. waterways, which primarily include inland and coastal vessel traffic, while the **Report on the Maritime Transport of Hazardous and Noxious Substances** focuses on intercontinental travel.

Implications:

Each analysis uses a different logic criteria to classify causes of spills. "The Human Element in Marine Safety" further expands this by starting a logic diagram that begins to establish a spill event tree. The MORT analysis in this study expands upon the event tree concept to provide a more detailed analysis of direct and root causes of spills. Further the direct causes in the MORT analysis and model contain all of the causes in the other studies. The MORT analysis expands on previous studies by establishing inter-relationships between the three primary direct causes and the root causes.

The vessel traffic data is also roughly equivalent to the traffic data in the **Report on the Maritime Transport of Hazardous and Noxious Substances**. The only exception is liquid gas carriers, which are not a choice in the vessel description section of the ERNS and MSIS data bases.

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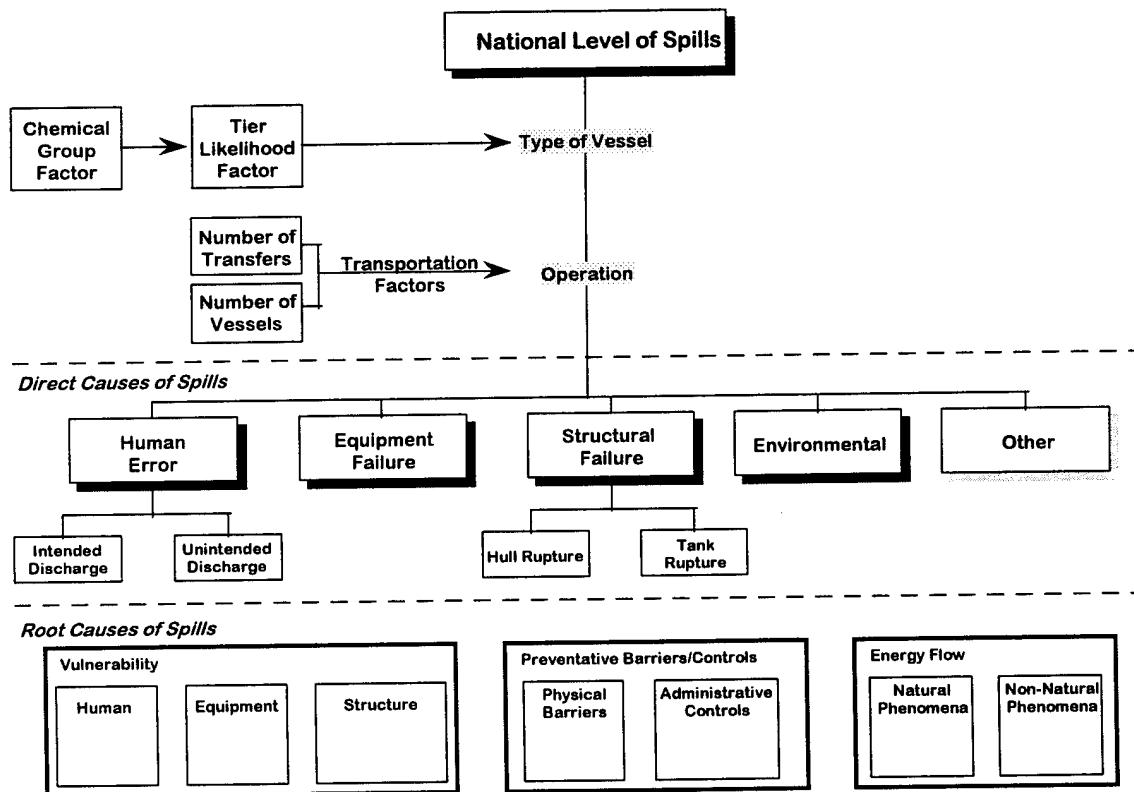
Appendix D

Conceptual Fault Tree of Causes of Spills

Using the MORT Analysis a Fault Tree of Causes of Spills Was Developed

Using the information from the MORT analysis, the Study Team developed a fault tree to characterize future spill incidents. The direct causes are divided into five categories: human error, equipment failure, structural failure, environmental, and other. The root cause consists of at least three events before leading to a direct cause. First, there must be a vulnerability, which is either a human, equipment, or structural focal point that can fail. Second, there must be a source of energy to act on the vulnerability. Third, there must be a barrier or control that fails to prevent the spill. Exhibit D-1 depicts this fault tree.

Exhibit D-1: Conceptual Fault Tree of Causes of Spills



This model can be used to show the interrelationships between spill events.

Appendix E

Listing of Identified Root Causes for MORT Model

Exhibit E-1: Energy Flows that Initiate Spill Incidents

Energy Flows	
Non-Natural Energy Flows	Natural Energy Flows
Sparks	Lightning
Chemical	Water
Corrosion	Rain
Collision	Heat
Allision	Cold/Ice
Pressure/pumping	Wind
Capsizing/Overturned	
Vessel Grounding	
Sinking	
Wave action/Washed overboard	
Vessel Pitched	
Power Failure	
Fire	
Explosion	

Exhibit E-2: Barriers/Controls that Failed

Barriers/Controls	
Physical Barriers	Administrative Controls
Alarms	Fail to Communicate
Pressure Release Valves	Fail to Shutdown
Shutoff Valves	Improper Application
Gauge	Improper Handling, General
	Improper Hose Handling
	Improper Installation
	Improper Maintenance
	Improper Operations, General
	Improper Securing
	Improper Sounding
	Improper Stowage
	Improper Training
	Improper Valve Operations
	Loading Multiple Tanks
	Topping Rate High
	Improper Transfer Operations

Exhibit E-3: Listing of Vulnerable Items Described at least Once in the Data Base as the Cause of a Spill

Vulnerabilities			
Human	Equipment	Structure	Weather
Inattention	Cut, Severing	Hull Rupture	Adverse Weather
Personnel Error, NEC	Excess, Wear	Tank Rupture	National Disaster
Illegal Dumping	Material Defect		
Vandalism/Sabotage	Normal Wear		
Ballast/Bilge Pumping	Overpressure		
COE-EPA Permit Release	Twisted, Kinked		
Emergency Discharge	Flange		
Waste Disposal	Gasket		
Tank Overflow	Hose Rupture, Leak		
	Load Arm Rupture, Leak		
	Manifold Rupture, Leak		
	Pipe Rupture, Leak		
	Pump Failure		
	Valve Failure		
	Well Blowout		
	Container, Tank Spill		
	NEC		
	Container/PKG Lost/Failed		